Weather impacts on natural, social and economic systems in the Netherlands

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Contents

Abstract

This study analyses the impact of weather variability on international tourism, outbreaks of fire, water consumption, energy consumption, and agriculture in The Netherlands. The aim is to obtain insight into the sensitivity and adaptability of these sectors to climate change. In addition, the public was surveyed as to their perception of (adaptation to) weather variability and climate change.

Nice weather stimulates outbound tourism in the following year, and stimulates inbound tourism in the current year. The survey reveals that people in The Netherlands are not aware of their changes in behaviour. Tourist destination choice of Dutch(wo)men is clearly influenced by climate considerations, but depends to a large extent on the planned vacation activities. For current holiday behaviour, there appears to be a world-wide optimal 24-hour temperature of about 21˚C.

Fire outbreaks are more frequent during hot and dry weather, and affect a larger area.

Water consumption increases during hot weather, and slightly so during dry weather. The survey suggests that people try to economise on their additional water use. Statistical analyses on daily, weekly and monthly time-scales yield broadly similar conclusions, although details differ and estimated models are very different.

Gas consumption decreases during mild winters. Electricity consumption is not affected by weather variability.

Yields of winter wheat and sugar beet increase after a dry winter. Both crops like warm weather. Summer wheat prefers wet winters. Potato yields fall with warm weather. Consumption potatoes prefer dry winters. Apple and strawberry yields, and pig populations are unaffected by the weather.

Storms occasionally create great havoc in the Netherlands and the UK. For instance, Daria in 1990 caused over 500 million Euro in insurance claims in the Netherlands, and over 2,500 million Euro in the UK. The relationship between wind speed and damage is exponential, so that a small increase in wind speed (as may well happen due to climate change) would lead to a great increase in damage.

People prefer hot and dry summer weather, and mild winters. They are not sure whether they would like to see more hot and dry summers, and they do not seem to like climate change.

1. Introduction

Richard S.J. Tol[1], Kees Dorland[2], Wietze Lise[2], Alexander A. Olsthoorn[2] and Frank A. Spaninks[2]

Much has been said and written about the impacts of climate change. Most of these studies are based on models, and thus only indirectly informed by observations. Similarly, most studies focus on change, and pay scant attention to variability. This study is an empirical study of the influence of weather variability on selected sectors. This report focuses on The Netherlands. Companion volumes study Germany (Flechsig *et al.*, 2000), Italy and the United Kingdom. These studies together form the EU-funded WISE project (Weather impacts on natural, social and economic sectors). Through this project, we hope to shed some light on the sensitivity of these sectors to the vagaries of the weather, and indirectly to climate change.

The approach of the Dutch team of the WISE project consisted of literature study (see the bibliography), data collection, and statistical analyses of the hypothesised relationships. This report focuses on the outcomes of the latter. The results of the literature survey are scattered throughout this report. An overview of the data collected is given in Table 1.1.

The approach is as follows. Sectors of interest were selected in a meeting of experts early December 1997 in Norwich. The sectors are international tourism, energy consumption, fire, water consumption, and agriculture.[3] First, a screening exercise was conducted, followed in selected cases by more in-depth analysis. The methodology for the screening exercise is given in Chapter 2. Its results are presented in the same chapter. Methodologies for the in-depth analysis are presented in separate chapters together with the results.

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2 Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands.

3 In a later meeting in Milan, mortality was added. This was not analysed for the Netherlands in the current study because it was extensively reported by Kunst *et al.* (1991, 1993), Mackenbach *et al.* (1991, 1993) and Martens (1998).

Table 1.1 Data at IVM for WISE. Data cover The Netherlands, unless indicated otherwise.

Category	Data	Unit	Freq.	Period	Source
Agriculture	Wheat	kg/ha	annual	03-96	CBS
		price	annual	47-96	CBS
		acre	annual	03-96	CBS
	Winter wheat	kg/ha	annual	03-96	CBS
		acre	annual	80-96	CBS
	Summer wheat	kg/ha	annual	03-96	CBS
		acre	annual	80-96	CBS
	Cons. Potato	kg/ha	annual	03-96	CBS
		acre	annual	03-96	CBS
	Ind. Potato	kg/ha	annual	80-96	CBS
		acre	annual	80-96	CBS
	Clay potato	kg/ha	annual	80-96	CBS
		price	annual	47-96	CBS
		acre	annual	03-96	CBS
	Sand potato	kg/ha	annual	80-96	CBS
		price	annual	61-96	CBS
		acre	annual	03-96	CBS
	Sugar beet	kg/ha	annual	80-96	CBS
		price	annual	47-96	CBS
		acre	annual	80-96	CBS
	Strawberry	kg/ha	annual	63-95	CBS
		price	annual	46-95	CBS
		acre	annual	63-95	CBS
	Apple	kg/ha	annual	63-95	CBS
		price	annual	46-95	CBS
		acre	annual	63-95	CBS
	Grape	kg	annual	64-95	CBS
	Pig	#	annual	36-96	CBS
	Piglet	#	annual	50-96	CBS
	Meat pig	#	annual	60-96	CBS
	Repro. Pig	#	annual	60-96	CBS
Tourism	People on holiday	#	annual	69-95	CBS
	Vacations	#	annual	69-95	CBS
	Vac. Domestic	#	annual	69-95[b]	CBS
	Vac. Abroad	#	annual	69-95[b]	CBS
	Expenditure	DGl.	annual	69-95[b]	CBS
	Exp. Domestic	DGl.	annual	69-95[b]	CBS
	Exp. Abroad	DGl.	annual	69-95[b]	CBS
	Survey		annual	87,92	CVO
	Int. travel[c]		annual	78-96	OECD
Energy	Gas use per sector[d]	m^3	monthly	71-97	EnergieNed
	Gas price	DGl/m^3	annual	77-96	
	Electricity use	KWh	monthly	57-97	EnergieNed
	Per sector[e]	KWh	annual	61-97	EnergieNed
	Electricity price	DGl/KWh	annual	57-94	
	Consumer price index	-	annual	61-96	
Drinking Water	Total	m^3	annual	50-95	CBS
	Groundwater	m^3	annual	50-95	CBS
	Infiltrated	m^3	annual	50-95	CBS
	Surface	m^3	annual	50-95	CBS
	Total[f]	m^3	daily	87-97	AWC
	Total[g]	m^3	daily	81-97	PWN
Fire	Total	#	annual	46-95	CBS
		DGl.	annual	50-95	CBS
	Houses	#	annual	46-95	CBS
		DGl.	annual	50-95	CBS
	Forests	#	annual	30-96	BosData
		hectare	annual	30-96	BosData

Table 1.2 Data at IVM for WISE. Data cover The Netherlands, unless indicated otherwise (continued).

Category	Data	Unit	Freq.	Period	Source
Storm	Storm damage	DGl.	event	87-92	CVS
	Stock-at-risk			87-92	Post Office
	Storm damage[h]	PS	event	87,90	General Accident
Climate	Temperature	C	Summer	06-96	CBS
	Temperature	C	Winter	06-96	CBS
	Temperature[i]	C	Daily	61-90	KNMI
	Temperature[i]	C	Daily	94-97	NOAA
	Temperature[i]	C	Monthly	61-80	KNMI
	Temperature[i]	F	Monthly	1706-90	NCAR
	Temperature[j]	F	Monthly	81-90	NCAR
	Precipitation[i]	Mm	Daily	81-90	KNMI
	Precipitation[k]	Mm	Daily	94-97	NOAA
	Precipitation	Mm	Monthly	34-39	SBB, IKC
				47-55	
				59-93	
	Precipitation	Mm	Annual	37-39	SBB, IKC
				47-55	
				59,62	
				69-71	
				74-93	
	Precipitation[l]	Mm	Monthly	various	NCAR
	Precipitation[m]	Mm	Monthly	91-95	KNMI
	Sunshine	Hours	Monthly	34-39	SBB, IKC
				47-55	
				59-93	
	Sunshine	Hours	Annual	37-39	SBB, IKC
				47-55	
				59,62	
				69-71	
				74-93	
	Evapotranspiration[o]	Mm	Monthly	59,62-93	SBB, IKC
	Evapotranspiration[o]	Mm	Annual	59, 62,	SBB, IKC
				65, 70,	
				74-84,	
				86-93	
	Windgust	m/s	Event	87-92	KNMI

[b] A substantial number of observations is missing.
[c] Data cover all OECD countries.
[d] Distribution companies, industry, power stations, total national use, export, total.
[e] Total industrial use, public transport, households, total electricity use, base metal, metallurgic, chemical, food, paper, refineries, textile, construction, other industry.
[f] Data for Amsterdam only.
[g] Data for North-Holland (excl. Amsterdam) only.
[h] United Kingdom.
[i] Stations De Bilt and De Kooy.
[j] Stations De Bilt, Schiphol, Vlissingen, De Kooy.
[k] Stations De Kooy, Schiphol, Soesterberg, Leeuwarden, Deelen, Eelde, Twente, Vlissingen, Rotterdam, Gilze-Rijen, Eindhoven, Volkel, Zuid-Limburg.
[l] Stations De Kooy (1844-1990), Schiphol (1981-1990), Hoofddorp (1735-1973), De Bilt (1849-1990), Groningen (1840-1977), and Eindhoven (1981-1990).
[m] Stations De Bilt and Schiphol.
[n] According to Penman.

2. Screening Exercise

Richard S.J. Tol[4]

The screening exercise followed a standard format for each sector. Annual indicators of these sectors' performance were retrieved from the Netherlands Central Bureau of Statistics (HTTP://WWW.CBS.NL). Average summer and winter temperature data were obtained from the same source. The average of the annual precipitation of five stations is used as a proxy for national precipitation, except for forest fire in which case precipitation in De Bilt was used. Performance indicators were regressed on a linear trend, current and past temperatures, and their own past, as follows:

$$I_t = \alpha_0 + \alpha_1 I_{t-1} + \alpha_2 t + \alpha_3 S_t + \alpha_4 S_{t-1} + \alpha_5 W_t + \alpha_6 W_{t-1} \tag{2.1}$$

where I is the indicator of interest, t is time, S is summer temperature, W is winter temperature, and the αs are parameters estimated by Ordinary Least Squares.

Results are presented by sector.

2.1 International tourism

A literature survey regarding number of holidays, holiday expenditures, and destination choice and their relation to weather and climate has been performed (cf. bibliography). Surprisingly, weather and climate do not figure prominently in the tourism literature. Anecdotical evidence and a limited number of empirical studies show that there is indeed a clear relationship between tourism demand and weather and climate. The surveyed literature does not, however, provide clear, quantified measures of changes in tourism demand and changes in weather and climate.

Annual, aggregate data on tourism was collected. A first statistical analysis indicates that the number of Dutch taking holidays is negatively influenced by the summer temperature of the year before. Surprisingly, the number of vacations taken is not or ambiguously influenced by temperature. Therefore, the first effect may be spurious. The number of foreign visitors is significantly higher in warm summers. See Table 2.1.

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Table 2.1 Regression results for Dutch tourist and tourism in the Netherlands.[a]

	Number of people[b]	Fraction of people	Number of vacations[b]	Number of vacations per person	Number of foreign visitors[b]
Constant	-0.48	3.89	-3.06	-0.16	-33.99
	(1.16)	(7.23)	(4.49)	(0.10)	(7.0)
Trend	0.07	0.43	0.12	0.01	0.42
	(0.03)	(0.17)	(0.07)	(0.00)	(0.09)
DV(-1)[c]	0.58	0.57	0.75	0.58	0.43
	(0.15)	(0.15)	(0.16)	(0.16)	(0.11)
T_{sum}			-0.17		1.17
			(0.11)		(0.37)
$T_{sum}(-1)$	-0.09	-0.67			
	(0.05)	(0.37)			
T_{win}				0.01	
				(0.00)	
Adj. R^2	0.97	0.96	0.98	0.97	0.96
N[d]	26	26	26	26	49

[a] Standard deviations are given in brackets.
[b] Millions.
[c] Dependent variable, lagged by one year.
[d] Number of observations in sample.

Micro-data were obtained to allow for a more in-depth analysis of the behaviour of Dutch tourists. These data are based on two surveys, in 1987 and 1992. The data sets each contain over 5,000 observations on holiday destinations, expenditures, and activities, and socio-economic characteristics. Also, aggregate data on tourist destination choice from OECD countries were obtained. These data sets are analysed in Chapter 3.

2.2 Fire

Annual data for fire and fire damages to buildings have been obtained. Higher summer temperatures increase the total number of fires. Higher winter temperatures increase the number of actions of the fire brigade. Fire in houses is not significantly influenced by temperature or precipitation. See Table 2.2.

Table 2.2 Regression results for fire.[a]

	Total[b]	Fire brigade[b,c]	Houses[b]
Constant	-35.47	-2.60	0.87
	(7.67)	(1.44)	(0.48)
Trend	0.52	0.05	
	(0.12)	(0.03)	
DV(-1)[d]	0.34	0.88	0.86
	(0.14)	(0.09)	(0.08)
T_{sum}	0.97		
	(0.44)		
T_{win}		0.16	
		(0.09)	
Adj. R^2	0.95	0.96	0.75
N[e]	44	44	44

[a] Standard deviations are given in brackets.
[b] Thousands.
[c] Number of actions by the fire brigade
[d] Dependent variable, lagged by one year.
[e] Number of observations in sample.

Fire in forests and other ‘natural’ areas have also been obtained. Lower than average precipitation, particularly during the summer, significantly increases the number of fires and the area burnt. See Tables 2.3 and 2.4.

Table 2.3 Regression results for forest fire.[a]

	Number of nature fires	Nature area burnt	Number of forest fires	Forest area burnt
Constant	912.02	1080.55	672.24	4150.72
	(151.73)	(289.92)	(151.55)	(693.37)
Trend	-5.34	-6.15	-5.24	-49.57
	(1.46)	(2.80)	(2.08)	(6.69)
P	-0.58	-0.83	-0.38	-1.53
	(0.18)	(0.34)	(0.13)	(0.81)
Adj. R^2	0.55	0.30	0.36	0.71
N[b]	25	25	23	25

[a] Standard deviations are given in brackets.
[b] Number of observations.

Table 2.4 Further regression results for forest fire.[a]

	Number of nature fires	Nature area burnt	Number of forest fires	Forest area burnt
Constant	1072.40	1064.70	748.95	3970.34
	(138.64)	(177.86)	(112.92)	(639.34)
Trend	-4.14	-3.41	-4.96	-32.77
	(1.30)	(1.67)	(1.47)	(6.01)
P_{jan}	-1.16	-0.81	-0.47	-1.44
	(0.72)	(0.92)	(0.52)	(3.31)
P_{feb}	-2.48	-2.09	-0.89	-13.21
	(0.88)	(1.12)	(0.59)	(4.04)
P_{mar}	0.91	-0.85	-0.63	0.94
	(0.82)	(1.05)	(0.55)	(3.80)
P_{apr}	-1.92	-1.72	-1.29	-6.32
	(1.01)	(1.30)	(0.65)	(4.67)
P_{may}	-0.99	-1.84	-0.54	-4.83
	(0.97)	(1.25)	(0.59)	(4.48)
P_{jun}	-2.18	-2.78	-1.28	-5.61
	(0.81)	(1.05)	(0.56)	(3.76)
P_{jul}	0.09	0.05	-0.16	-0.93
	(0.61)	(0.78)	(0.40)	(2.81)
P_{aug}	-1.00	-1.95	-1.00	-4.28
	(0.70)	(0.90)	(0.44)	(3.22)
P_{sep}	-1.10	-1.28	-0.42	-1.32
	(0.77)	(0.99)	(0.51)	(3.57)
Adj. R^2	0.46	0.48	0.45	0.52
N[b]	50	50	35	50

[a] Standard deviations are given in brackets.
[b] Number of observations.

2.3 Water consumption

An analysis of annual, national data indicates that water use is higher in warm summers. The estimated influence of lagged temperatures is largely compensated by the estimated influence of lagged water consumption. See Table 2.5.

For a more in-depth study, we acquired time series of daily production of drinking water in the period 1981-1997 for the province of North Holland. These data are analysed in Chapter 4.

2.4 Energy consumption

An analysis of annual, national data indicates that electricity use is not significantly influenced by temperature, as air conditioning and electric heating are not widespread in The Netherlands. Gas use goes up in cold winters, and the year after a warm summer. The latter effect is not significant in gas applied for heating. See Table 2.5.

Table 2.5 Regression results for water and energy.[a]

	Water	Electricity	Domestic gas	Gas for electricity
Constant	129.37	-6580.63	-17358.97	3904.71
	(83.53)	(3325.20)	(11903.65)	(880.37)
Trend	-5.34	170.84	201.06	243.23
	(1.46)	(72.14)	(84.30)	(94.68)
DV(-1)[b]	0.99	0.93	0.67	0.44
	(0.01)	(0.04)	(0.17)	(0.19)
T_{sum}	10.73			
	(3.11)			
$T_{sum}(-1)$	-9.91		1014.88	
	(3.15)		(433.09)	
$T_{sum}(-2)$	-6.80			
	(3.21)			
T_{win}			-674.10	-630.56
			(253.04)	(249.37)
Adj. R^2	1.00	1.00	0.36	0.49
N[c]	45	48	23	17

a Standard deviations are given in brackets.
b Dependent variable, one year lagged.
c Number of observations.

For a more in-depth study, monthly and yearly time series of national gas and electricity use, from 1971 to 1997 and 1957 to 1997 respectively, have been obtained from the Dutch energy association (*EnergieNed*). Monthly gas use data is available for distribution companies, industry, power stations and export separately. Monthly electricity use data is available for the total electricity use only. Yearly electricity use data is available for public transport, houses and 9 industrial sectors separately. Furthermore, time series of daily mean temperature from 1961 to 1990 were obtained from KNMI (1982ff, 1991, 1992ff), and from 1994 onwards from NOAA (http://ingrid.ldgo.columbia.edu). This temperature data was used to calculate the so called ‘degree days’. The degree-days are used especially for energy planning by gas companies. The first statistical analyses indicate that temperature significantly affects gas consumption, and can explain most of the variation in gas consumption. The annual cycle and weather anomalies have not yet been separated out, however.

2.5 Agriculture

Annual data for yield, acreage and price of wheat (all, winter, summer), potatoes (sand and clay, domestic and industrial), sugar beet, strawberry, and apples, and annual data for pig and piglet population have been collected. Wheat grows better in warm winters, and worse in dry summers. Winter wheat is negatively affected by wet winters and hot summers; surprisingly, winter wheat grows better the year after a hot summer. Summer wheat benefits from wet winters. Sugar beet prefers dry and warm winters. Strawberry yields are positively affected by the temperature and precipitation of the previous summer. This may reflect adaptation, but a more likely explanation is that the data are incorrectly reported. Apple yields are not significantly influenced by the weather. See Table 2.6.

Adult pig populations are not significantly affected by the weather. However, there are more young pigs the year after a warm summer, and more after a cold winter. Claygrown potatoes and potatoes for industrial use yield less in warm summers. Sand-grown potatoes dislike warm weather even more, whether current or in the recent past. Potatoes for human consumption yield less in warm summers and in wet winters. See Table 2.7.

Price and acreage of the selected crops do not show significant correlation with the weather (results not shown). The price of apple, strawberry, and sugar beet is affected by their supply (results not shown). The acreage of apple, consumption potato, strawberry, and sugar beet is affected by their price and yield in the previous year (results not shown).

Table 2.6 Regression results for wheat, sugar beet and fruit yields.[a]

	Wheat[b]	Winter wheat[b]	Summer wheat[b]	Sugar beet[b]	Strawberry[c]	Apple[c]
Constant	6.90 (2.25)	82.78 (85.62)	151.24 (21.95)	163.36 (249.54)	-10.45 (4.26)	-6.54 (4.29)
Trend	0.17 (0.04)	1.51 (0.25)	1.21 (0.23)	7.59 (3.66)	0.07 (0.03)	0.20 (0.08)
DV(-1)[d]	0.74 (0.07)	0.48 (0.07)	0.36 (0.07)	-0.49 (0.28)	0.24 (0.15)	0.48 (0.17)
T_{sum}		-7.17 (3.78)				
$T_{sum}(-1)$		6.91 (3.76)			0.46 (0.29)	
T_{win}	0.77 (0.29)					
$T_{win}(-1)$				9.81 (10.00)		
P_{sum}[e]	-0.23 (0.07)					
$P_{sum}(-1)$[e]					1.05 (0.32)	
P_{win}[e]		-0.87 (0.53)	1.44 (0.67)	-3.96 (2.01)		
$P_{win}(-1)$[e]				-6.18 (2.46)		
1980ff[f]		-154.03 (19.55)	-190.62 (22.97)			
Adj. R^2	0.94	0.90	0.85	0.68	0.60	0.66
N[g]	88	88	88	15	32	32

[a] Standard deviations are given in brackets.
[b] 100 kg/ha.
[c] kg/ha.
[d] Dependent variable, lagged by one year.
[e] Precipitation is measures in hundredths of millimetres. Precipitation is corrected for its correlation with temperature. $P_{sum} = C - 291.12\ (78.36)\ T_{sum}$; adj. $R^2 = 0.12$. $P_{win} = C + 158.82\ (33.75)\ T_{win}$; adj. $R^2 = 0.19$.
[f] There is an unexplained level shift in yields of winter and summer wheat from 1980 onwards.
[g] Number of observations in sample.

Table 2.7 Regression results for potato yields and pig population.[a]

	Pig[b]	Piglet[b]	Clay potatoes[c]	Sand potatoes[c]	Consumption potatoes[c]	Industrial potatoes[c]
Constant	-1053.98	-1699.43	316.71	592.21	245.63	-374.34
	(374.07)	(621.64)	(76.90)	(156.02)	(31.61)	(174.40)
Trend	27.94	17.32	3.85	8.65	1.48	6.40
	(8.75)	(7.47)	(1.05)	(1.86)	(0.25)	(2.12)
DV(-1)[d]	0.92	0.89	0.29	-0.61	0.19	-0.04
	(0.03)	(0.06)	(0.15)	(0.27)	(0.10)	(0.20)
T_{sum}			-21.11	-21.13		-29.99
			(3.70)	(4.71)		(8.40)
$T_{sum}(-1)$		66.88		-13.88		
		(35.41)		(6.69)		
T_{win}				-5.91	-2.65	
				(3.03)	(1.42)	
$T_{win}(-1)$		-68.32		-7.70		
		(18.99)		(3.57)		
P_{win}[e]					-1.67	
					(0.82)	
Adj. R^2	0.99	0.99	0.80	0.72	0.57	0.66
N[f]	57	45	15	15	88	32

[a] Standard deviations are given in brackets.
[b] 1000s.
[c] 100 kg/ha.
[d] Dependent variable, lagged by one year.
[e] Precipitation is measures in hundredths of millimetres. Precipitation is corrected for its correlation with temperature. $P_{sum} = C - 291.12\ (78.36)\ T_{sum}$; adj. $R^2 = 0.12$. $P_{win} = C + 158.82\ (33.75)\ T_{win}$; adj. $R^2 = 0.19$.
[f] Number of observations in sample.

3. International Tourism

Wietze Lise[5], Frank A. Spaninks[5] and Richard S.J. Tol[6]

3.1 Introduction

Tourism has become the biggest industry in the world (*The Economist*, April 10, 1999, p. 31) and many countries rely heavily on the revenue of this industry. This is not reflected in the attention research pays to it. This is due to the lack of adequate data and the special nature of tourism demand (O'Hagan and Harrison, 1984). Only a few studies make a link with climate change, while it can be argued that climate is obviously important for international tourism. Many tourists find it important to have a high chance on sunny and warm weather at their holiday destination, in order to relax by swimming, sunbathing and wandering around in foreign places. Yet, it is not known just how important climate is.

The larger part of the literature on tourist destination choice (see Crouch, 1995, Lim, 1997, and Witt and Witt, 1995, for surveys) takes the climate of tourist's homes and destinations for granted, focusing on factors such as prices and expenditures, and sociological and psychological considerations. In addition, these studies are mainly interested in the short run, in which climate is constant. In the longer run, however, climate is changing, and increasingly rapid so due to human activities, particularly fossil fuel combustion (Houghton *et al.*, 1996). The tourism industry is accustomed to rapid change. Nevertheless, climate change could have major implications for the tourist industry, for instance, by making currently popular areas less attractive and bringing new competitors to the market. This chapter investigates the sensitivity of tourists in their choice of destination with respect to climate change. This is new. First a general picture is obtained of the link between tourist demand and temperature. Next the general picture is unravelled for the case of Dutch tourists to study the link between tourist activities during holiday trips and temperature.

The analysis of this chapter is based on data sets on two levels. On the micro level, data were purchased from the CVO (Foundation for Continuous Vacation Surveying). The micro-data consists of over 6,000 trips of Dutch tourists who are asked for their tourist destination (country of residence or abroad) and about their activities during their visits. The data includes characteristics such as age-cohort, income-cohort, total holiday cost, departure date, destination-code and duration of stay. These micro-data cover only 1988 and 1992, because of research budget constraints. In addition, on the macro level, time-series on tourist numbers, destinations, and expenditures at the aggregate, national level are readily available, from sources such as the World Bank, the OECD and national sta-

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tistical services. Climate and weather data are obtained from various sources, including tourist guides and IIASA's global climatology.

This chapter is organised as follows. Section 3.2 briefly reviews the literature on tourist destination choice, and the few studies that look into the relationship between climate (change) and tourism. The chapter then continues with a statistical analysis at two levels, namely at the country level (Section 3.3) and at the individual level (Section 3.4). More specifically, Section 3.3 analyses international tourist flows, to explore the sensitivity of tourism to climate change in general and global warming in specific. Thereupon, first all tourist arrivals are pooled country-wise to study a general global trend. Second, eight individual countries of tourist origin and their travel destination are considered to verify to which extent tourist destination choice is country specific. Finally, a more detailed analysis is performed for Dutch tourists by aggregating a micro data set for Dutch tourist, to explore whether the demand for Dutch tourists differs from the demand for British tourists. The CVO data is studied at the individual level with a factor and regression analysis (Section 3.4). It turns out to be a fruitful way to study independent choice situations by converting binary choice variables into continuous variables. Moreover, Section 3.4 studies the link between tourist activities and climate change by comparing winter and summer tourists, to see whether there are any differences in their choice behaviour, using a factor and regression analysis. Section 3.5 concludes by highlighting the main findings from both the macro- and the micro analysis and placing these in the context of global climate change.

3.2 Literature survey

3.2.1 Tourist destination choice

The number of studies devoted to tourist demand is vast, but the impact of climate and climatic change on tourism receives remarkably limited attention. There are a number of recent studies with a general focus on tourism demand (Lim, 1997, Martin and Witt, 1989, Smeral and Witt, 1996, and Witt and Witt, 1995), and with a regional focus (Bakkal and Scaperlanda, 1991, Divisekara, 1995, Eymann and Ronning, 1997, Hannigan, 1994, Melenberg and Van Soest, 1996, Opperman, 1994, Pack *et al.*, 1995). This section focuses on tourist destination choice alone, to provide an impression on the main results from the literature.

Witt and Witt (1995) survey empirical research on tourism demand to conclude that 'it is not possible to build a single model which is appropriate for all origin destination pairs' (Witt and Witt, 1995, p. 469). Their finding is confirmed by Crouch (1995) who concludes from his meta-analysis that tourism demand is indeed situation-specific. The analysis of this chapter confirms this conclusion although, at the same time, some remarkable generalities are found.

Lim (1997) reviews existing studies on tourism demand which use regression techniques. Most models are based on yearly data time series, which are linear or loglinear, mainly including economic variables. The lack of sufficient data is seen as a clear limitation of these models. Usage of yearly data does not capture the volatile character of the tourism sector; even the length of time series cannot compensate for this. Alternatively, cross section data could be used to focus on linkages between tourist choices and economic and climate data, which is the approach of this chapter.

Ryan (1991) argues that time series on tourism are susceptive to variation in macroeconomic growth which may lead to heteroscedasticity: in times of recession tourism appears to be income inelastic, while in times of growth tourism becomes income elastic. Ryan (1991) provides a qualitative approach to tourist choices. The choice to travel and its destination is not a fixed and stable process. Tourism is a fast changing industry, which has come about recently and is now a major industry. There are many interlinked processes such as economic demand, social demand and psychological factors such as time availability and the need to escape from the daily routine in an organised versus adventurous manner. Psychological considerations can explain a great deal of recent changes in tourist considerations and is according to Ryan the most important aspect for explaining tourism demand. Quantitatively, a factor analysis can be used to analyse data sets on psychological responses for tourist actions at holiday destinations (see Section 3.4.1).

3.2.2 Climate (change) and tourism

In studies on tourist destination choice, some stressed the need for and incorporated climatic components in their analysis. Barry and O'Hagan (1972) study British tourist expenditure in Ireland and include a weather index in the descriptive variable list. Their weather index turns out to be always insignificant, rejecting it as an important consideration for tourists in their travel destination selection.

Syriopoulos and Sinclair (1993) study the choice of British, German, American, French and Swedish tourists for a destination in a Mediterranean country: Greece, Spain, Portugal, Italy and Turkey using the AIDS (almost ideal demand system) model. They use time series from 1960-87 and consider several types of costs. They study price elasticities between tourists from 'cold' countries to 'warm' countries, which are typical climate considerations. They find that destinations which recently have gained popularity (Greece, Portugal and Turkey) have a high expenditure elasticity, indicating 'a likely increase in their future shares of a higher origin country expenditure budget' (ibid. p. 1551). The expenditure elasticity for Spain and Italy are lower, indicating that they require change in their tourism products 'if they are to capture a higher share of the tourism expenditure' (ibid.).

Various authors look at the impact climate change would have on skiing, e.g., Wall (1988) for Canada. Gable (1997) looks at the implication of climate change and sea level rise for tourism supply in the Caribbean. UKCCIRG (1991, 1996) qualitatively discuss the impact of climate change on tourism in Great Britain. Agnew (1997) looks at the quantitative impacts of weather variability on tourism in the UK. Mendelsohn and Markowski (1999) and Loomis and Crespi (1999) investigate the impact of climate change on outdoor recreation in the USA.

In the knowledge of the authors of this chapter, Maddison (1998) is the only quantitative study that looks at tourist destination choice in the context of climate change. Using a pooled travel-cost model, he estimates the importance to British tourists of climate at the holiday destination. Maddison (1998) also calculates the change in consumer surplus for certain climate changes. Maddison's model is adapted for Dutch tourists in Section 3.3.

3.3 Sensitivity of tourist demand to climate change

3.3.1 Global perspective

To study the sensitivity of tourist demand to climate change at the international level, data from the World Development Indicators CD-ROM (World Bank, 1998) on the total numbers of tourist arrivals and departures per country is used. The origin and the destination of these tourists are not provided, however. As a result, travel distances and costs are unknown. Nevertheless, such data can be used to estimate which factors are decisive for making a country of destination popular (high number of visitors). Climate is represented by the average temperature of the warmest month. The IIASA database for mean monthly values of temperature, precipitation and cloudiness on a global terrestrial grid by Leemans and Cramer (1991) is used. The climate of the capital of a country is assumed to be representative for the entire country. The crudeness of the analysis is compensated by the fact that there are data for 17 years (1980-1996) for 210 countries. In order to test that there is a global optimal temperature, all data are pooled together and treated as cross-section data.

The estimated model is:

$$\mathrm{LN}ARRIVALS = \beta_0 + \beta_1 YEAR + \beta_2 AREA + \beta_3 GDPPC + \beta_4 TW + \beta_5 TW^2 + \text{error} \qquad (3.1)$$

Table 3.1 defines the variables.

The variable *YEAR* is included to filter out all unexplained trends. The variable *AREA* incorporates that bigger countries can receive more tourists. This is only true in a limited sense, as a lot of tourists can be accommodated in a small place. The variable *GDPPC* captures destination price levels as well as tourist's dislike for poverty. *TW* is the climate variable. The first two columns of Table 3.3 present the results.

Not surprisingly, the explanatory value of the model is low (an R^2 of 0.43). The results are convincing, because the estimates of the parameters of major interest (temperature) are plausible (see below), stable over the sample, and robust to variations in the model specification.

Table 3.1 Definition of the variables used.

Variable	Description
AGE	Average age of the interviewed tourists (years)
AREA	Land surface area per country (km^2)
COAST	Total length of the coast of a destination country (km)
DIST	Distance (as the crow flies) between capitals (km)
DUR	Number of days spent on holiday (number)
GDPPC	Country-wise PPP-based per capita income (US $ per year)
INCOME	Average income of the interviewed tourists (Dutch guilders per year)
LN*ARRIVALS*	Natural logarithm of the number of international tourist arrivals per country per year
LN*VISITS*	Natural logarithm of the number visits to a destination country by a Dutch tourist
PDAY	Average daily expenditure per person (Dutch guilders per day)
PERSON	Number of persons travelling (number)
POP	Total population (number)
POPDEN	Population density (number per square km)
PRECIP	Mean precipitation in the quarter of travelling (inch per month)
*Q*1	Dummy for the first quarter (winter)
*Q*2	Dummy for the second quarter (spring)
*Q*3	Dummy for the third quarter (summer)
SUN	Mean sun hours in country of destination in the quarter of traveling (hours per day)
TW	Mean temperature of the warmest month per country (^oC)
TQ	Mean temperature in the quarter of traveling (^oC)
YEAR	Year of observation

The inclusion of both temperature and temperature-squared implies that there is an optimal summer temperature for tourism. The optimal temperature (T^{opt}) and its standard deviation ($\sigma_{T^{opt}}$) can be approximated with the following formulae, which is the first-order Taylor expansion, where the β's are the related regression coefficients:

$$T^{opt} = \frac{\beta_T}{2\times\beta_{T^2}};\sigma_{T^{opt}} = \frac{1}{2}\times\left(\frac{\sigma_T}{\beta_T}+\frac{\sigma_{T^2}}{\beta_{T^2}}\right)\times T^{opt} \tag{3.2}$$

It turns out that the optimal temperature is about 21 degrees centigrade, with a standard deviation of 2; cf. Table 3.3. This seems fairly reasonable (recall that this is the average over day and night temperatures (*TW*)). The optimal temperature corresponds to the present temperatures found in northern Spain, southern France, northern Italy, the former Yugoslavia and Uganda. The first three are well-known tourist resorts, former Yugoslavia used to be, and Uganda may become one.

The optimal temperature occurs in countries with many beaches. It may be that tourists care more about the presence of the beach than about the climate. The implications of climatic change would then be dramatically different. To test this, the length of a tourist's destination's coast is added as an explanatory variable. The variable *AREA* is then insignificant – there is a high correlation between *AREA* and *COAST*. Table 3.3 displays the results. Table 3.3 shows that the estimated influence of temperature on international tourist arrivals is independent of whether *AREA* or *COAST* is used as an explanatory variable. The optimal holiday temperature is virtually the same. In fact, the correlation between coastal length and temperature is quite low. Both beaches and nice weather attract tourists.

3.3.2 Tourist behaviour from different origin countries

The above model gave a general picture about tourists of all origins. It may be, however, that tourists from different nationalities have different tastes for the climate of and the distance to their holiday destination, as is indeed found by Crouch (1995) and Witt and Witt (1995). Data are a real constraint. The OECD publishes data on tourist destinations and origins for selected countries. Their 1997 report (OECD, 1997) is used, which has data for the period 1984-1995, for the countries listed in .Table 3.2. For the Netherlands, the more detailed internet-database of the Central Bureau of Statistics is used (http://www.cbs.nl), covering 1970 to 1995 and more European countries (the destinations Canada and Japan are added from the OECD data). The data are the total, annual number of, say, Dutchmen or Italians arriving in, say, France or Germany. There are many missing observations; some countries report on the basis of residence, others on nationality; and some countries only count visitors whereas others count tourists separately. Data so crude only allow for a simple model to be estimated. As before, the purpose is to test whether there is an optimal temperature by treating the time-serial as cross-section data.

Table 3.2 The countries which are included in the analysis.

Both in 1988 and 1992	Australia, Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Indonesia, Ireland, Israel, Italy, Luxembourg, Malta, Morocco, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Tunisia, Turkey, United Kingdom
Only in 1988	Bulgaria
Only in 1992	Iceland, New Zealand, Slovenia

The estimated model per origin country is:

$$\mathrm{LN}ARRIVALS = \beta_0 + \beta_1 YEAR + \beta_2 DIST + \beta_3 TW + \beta_4 TW^2 + \mathrm{error} \tag{3.3}$$

Table 3.1 defines the variables. Table 3.3 presents the estimated parameters and a summary of the results. The estimated optimal temperatures for the individual countries do not deviate significantly from the world estimate of 21ºC. The optimal temperature varies between Americans who prefer 20.3ºC and French who prefer 22.4ºC; this difference is not statistically significant. Although he uses different climate indices, Maddison's climate optimum (for the British) is also found in the European part of the Mediterranean (Maddison, 1998). The optimal holiday climate appears to be independent of the tourist's home climate.

Table 3.3 Regression results for the global and national tourist destination models.[a]

	World	World	Canada	France	Germany	Italy	Japan	Netherlands	UK	USA
Constant	-68	-62	-3.3	-107	-168	-190	-184	-64	-103	-6.4
	(15)	(14)	(60.0)	(50)	(46)	(55)	(66)	(15)	(46)	(43.3)
YEAR	0.037	0.035	-6.5E-4	0.052	0.084	0.094	0.090	0.030	0.051	0.0032
	(0.007)	(0.007)	(0.030)	(0.025)	(0.023)	(0.028)	(0.033)	(0.007)	(0.023)	(0.0021)
AREA	1.7E-7									
	(0.2E-7)									
COAST		8.3E-5								
		(0.6E-5)								
GDPPC	2.2E-4	2.1E-4								
	(7.1E-6)	(7.1E-6)								
DIST			-2.8E-4	-2.8E-4	-2.4E-4	-2.6E-4	2.1E-4	-3.5E-4	-1.5E-4	-2.0E-4
			(0.3E-4)	(0.1E-4)	(0.1E-4)	(0.2E-4)	(1.4E-4)	(0.4E-4)	(0.1E-4)	(0.2E-4)
TW	0.46	0.47	1.7	1.7	1.5	1.7	1.5	1.0	1.5	1.5
	(0.04)	(0.04)	(0.2)	(0.1)	(0.1)	(0.1)	(0.2)	(0.2)	(0.1)	(0.1)
TW^2	-0.011	0.011	-0.040	-0.038	-0.035	-0.039	-0.035	-0.023	-0.034	-0.037
	(0.001)	(0.001)	(0.005)	(0.004)	(0.003)	(0.004)	(0.005)	(0.006)	(0.003)	(0.003)
Optimal *TW*	20.9	21.4	21.3	22.4	21.4	21.8	21.4	21.7	22.1	20.3
	(1.9)	(1.9)	(2.6)	(1.8)	(1.6)	(1.8)	(3.0)	(5.0)	(1.7)	(1.5)
# Observations	1730	1730	158	156	170	140	145	414	157	159
R^2	0.43	0.43	0.62	0.80	0.75	0.77	0.51	0.31	0.68	0.62

[a] Regression of the natural logarithm of the number of arrivals in a country, either from all other countries (world) or from a particular country (Canada to USA). Standard deviations are given in brackets.

If the number of arrivals (rather than its natural logarithm) is used as a dependent variable, the estimated climate optimum is somewhat different, but not significantly so. Note that, in the linear model, the climate optimum for tourists from Canada and Japan cannot be estimated with any accuracy. Since the results of the macro analysis are quite crude, it is useful to undertake a more detailed with micro data. Thereupon aggregated Dutch micro data are at the basis of the analysis in the next section.

3.3.3 International demand of Dutch tourists

To find the demand of Dutch tourists, a pooled travel cost model is estimated using CVO data for Dutch tourists. This model is set up to figure out which variables boost the number of tourists a certain destination can attract. For that, the CVO data set is aggregated into quarterly data per destination.

Each destination has a number of characteristics, like distance, airfare to reach that destination, temperature, rainfall and hours of sunshine. Climate data (temperature, precipitation and sun) were obtained from http://the.shopping–centre.com/travel/menus/weather.html, a standard source of such data for tourists and tourist operators. Climate data are quarterly (January-February-March, April-May-June, July-August-September, October-November-December). Following Maddison (1998), the distance between Amsterdam and the capital of the country of destination is based on the great circles distance (see http://www.indo.com/distance/). The CVO data only contains a variable on the total travel expenditure. To approximate the expenditure at the destination the cheapest airfare to a destination is taken as a proxy for the travel cost (see http://www.airfair.nl) to filter out the travel cost. Travel cost is excluded from the analysis because of its similarity to distance; their high correlation causes multicollinearity.
It is assumed that each person, either travelling in a group or alone, pays the same (minimum) airfare. Neglecting travellers who are prepared to pay more for travelling, it also neglects that tourist destinations can also be reached by other modes of transport. It is also assumed that the travel cost cannot exceed 80% of the total expenditure on a holiday. This last assumption is required, because in some exceptional cases the calculated travel cost can exceed the total expenditure on a holiday. Following the reasoning above, the same set of variables as Maddison (1998) can be derived. The analysis is carried out for tourists only. After deleting all destination countries with missing data, and by considering four seasons, 89 observations remain for 1988 and 96 observations for 1992.

Table 3.2 shows the countries that are included in the analysis. Table 3.1 defines the variables that are included in the analysis.

The following tourist demand equation is estimated to find which variables contribute most to the number of tourists a certain country attracts. This model is also known as the pooled travel cost model.

$$
\begin{aligned}
\mathrm{LN}VISITS_d &= \beta_0 + \beta_1 GDPPC_d + \beta_2 POP_d + \beta_3 POPDEN_d + \beta_4 CC \\
&\beta_5 PDAY_d + \beta_6 DIST_{d-o} + \beta_7 TQ_d + \beta_8 PRECIP_d + \beta_9 Q1 + \beta_{10} Q2 + \beta \\
&\beta_{12} INCOME_o + \beta_{13} AGE_o + \text{error}
\end{aligned}
\tag{3.4}
$$

Subscript *d* denotes tourist destination; subscript *o* represents the origin; for instance, if a Dutchman goes to France, *d=France* and *o=Netherlands*. This model is different from Maddison's model to avoid the impact of multicolinearity, which leads to insignificant results because of the (aggregated) data set for the Netherlands is small. The gross domestic product per capita is used instead of the gross domestic product that is highly correlated with the population in a country (see Table 3.4). The square of temperature is omitted, because its coefficient did not become significant in the regression equations, which may be caused by its high correlation with temperature and low number of observations. Staying as close as possible to Maddison's model enables a crosscheck with his' results. Age and income are added to the descriptive variable list as suggested by Maddison in his' conclusions. These changes in the model improved the estimation result considerably.

Table 3.4 Important correlation coefficients in the aggregated data set.

Variables	1988	1992
GDP & *POP*	0.603	0.709
DIST & travel cost	0.777	0.831
TQ & TQ^2	0.961	0.950

Table 3.5 summarises the main statistics of the estimated equations. An interesting outcome is that the correlation between age/income and the number of visits is insignificantly positive in 1988. The correlation becomes negative in 1992 and significantly so for age. The negative coefficient on *AGE* is as expected. This indicates that the increase in tourism demand is caused by young people, who are less rich, but not significantly so. This means that, more recently, younger people go to the more popular destination, where the number of visits is high. It is also remarkable that the significance level of temperature has fallen from 99% to 91% in 1992. This deterministic analysis indicates that traditionally sunny places will see a reduction of tourism demand in the case of global warming. All other included variables do not change significantly between 1988 and 1992. Maddison estimated the following model (where the significant variables have their signs in brackets):

$$\begin{aligned}
&\mathrm{LN}VISITS_d = \beta_0 + \beta_1 FARE_{d-o}(-) + \beta_2 GDP_d(+) + \beta_3 POP_d(+) \\
&\beta_4 POPDEN_d(-) + \beta_5 COAST_d(+) + \beta_6 PDAY_d(-) + \beta_7 DIST_{d-o} \\
&\beta_8 T_d(+) + \beta_9 T_d^2(-) + \beta_{10} PRECIP_d + \beta_{11} Q1 + \beta_{12} Q2 + \beta_{13} Q3 + \mathrm{er}
\end{aligned} \tag{3.5}$$

Comparing the results of this chapter with the outcome of Maddison, population density and the beach length are insignificant here, while distance is negatively significant. This indicates that the amount of beaches and the population density does not matter for Dutch tourists, while it matters for British tourists. Further, the regression result indicates that Dutch tourists prefer a shorter distance to the holiday destination, while British tourists do not have such a preference. The signs of *GDPPC*(+), *POP*(+), *PDAY*(–) and *TQ*(–) are significant and the same. Hence, it indicates that tourism demand for Dutch and British tourists is higher for richer, and larger countries, which are cheaper and the temperatures are higher.

Table 3.5 Log-linear regression of climate on the number of visitors in a country.

	1988			1992		
	Coefficient	Standard deviation	Significance	Coefficient	Standard deviation	Significance
Constant	-1.80	1.35	0.19	3.35	1.36	0.02
GDPPC	1.80E-04	3.92E-05	0.00	1.75E-04	3.50E-05	0.00
POP	1.74E-08	4.40E-09	0.00	2.00E-08	4.36E-09	0.00
POPDEN	1.29E-03	8.76E-04	0.15	3.44E-04	8.26E-04	0.68
COAST	-3.10E-05	4.13E-05	0.45	-3.80E-05	3.94E-05	0.34
PDAY	-0.0111	0.0034	0.00	-7.98E-03	2.98E-03	0.01
DIST	-3.70E-04	9.32E-05	0.00	-1.60E-04	7.46E-05	0.03
TQ	0.140	0.038	0.00	0.0596	0.0343	0.09
PRECIP	0.037	0.126	0.77	-0.092	0.108	0.39
*Q*1	0.474	0.453	0.30	-0.360	0.451	0.43
*Q*2	-0.644	0.501	0.20	-0.390	0.468	0.41
*Q*3	-0.612	0.544	0.27	-0.279	0.534	0.60
INCOME	7.78E-06	1.99E-05	0.70	-3.20E-05	2.12E-05	0.14
AGE	0.0109	0.0185	0.56	-0.0470	0.0158	0.00
Adjusted R^2		0.44			0.41	
# observations		90			97	

3.4 Sensitivity of tourist activities to climate change

3.4.1 Behaviour of Dutch winter and summer tourists in 1988 and 1992

To analyse the behaviour of Dutch tourist in the winter and summer season, a factor analysis is carried out on the set of twenty-five dummy variables concerning the choice of activity during a holiday, to reduce this set into independent activity-choices and to indicate the priorities. In a standard factor analysis (Harman, 1967), as a rule of thumb, factor loadings greater than or equal to 0.5 in absolute terms, are called dominating factors; these factors symbolise the main considerations in a decision. When the dominating factor loading is negative the indicator works the other way around. For example, a negative factor loading for using a car means that not using a car is an important consideration. Tables 3.9 and 3.9 show the dominating factors of each principal component for winter (from October until April) and summer tourist (from May until September) in 1988 and 1992. The rotated factor matrix is used here to maximise the factor loadings, so that the most possible distinct choice patterns is obtained in each case. A factor analysis helps in determining the main and independent considerations for going on a holiday, while comparing a normal winter (1992) with a soft winter (1988) and a normal summer (1988) with a hot summer (1992) accounts for the possible impact of climate change. Table 3.6 shows the weather characteristics for these specific years. Table 3.7 shows that the data set consists of two thirds of summer tourists. Business trips are excluded from the data set.

Table 3.6 Weather characteristics in the Netherlands

	Winter	Summer	Year
Sunshine (hours, cumulative)			
1987	143	444	1312
1988	113	447	1293
1991	192	587	1566
1992	172	620	1599
Precipitation (mm, cumulative)			
1987	1610	3250	9270
1988	2830	2260	8870
1991	1444	2277	7161
1992	1366	2936	9565
Temperature (degree Celsius, average)			
1987	1.5	15.6	8.9
1988	5.0	15.8	10.3
1991	2.2	16.6	9.5
1992	3.9	17.8	10.5

Table 3.7 Number of observations for winter and summer tourists.

Year	Summer tourists	Winter tourists	All tourists	Total data set
1988	3504 (68%)	1622 (32%)	5126	6659
1992	3763 (67%)	1839 (33%)	5602	6757

There is a great similarity in behaviour of Dutch summer tourists in 1988 and 1992. Factor 1, 2, 6 and 9 are the same. Hence, in both years the most important activity for Dutch summer tourists is sunbathing. After that, sightseeing has the highest priority. Water sports gets the sixth priority, while walking gets the ninth priority. There is also a great similarity between factor 3, 4 and 7. The third priority is given to leave the car home and travel by other means of transport; in 1988 this is accompanied by a café visit. The fourth priority is given to visiting an attraction; in 1988 this is combined with horse riding. The seventh priority is given to skiing; in 1988 this is combined with tennis and in 1992 it is combined with a café visit. The main change in behaviour between 1988 is factor 5 on travelling by car without cycling, which activity has disappeared in 1992. Instead tennis and midget has given the fifth priority in 1992. Finally, the combination of factor 8 in 1988 (golf and sauna) resembles factor 10 in 1992 (add theatre visit). Hence, the behaviour of summer tourists does not change much between a hot summer (1992) and a normal summer (1988). In indicates for both years that sunbathing, sightseeing and travelling are the three most important activities during a holiday for Dutch tourists. That the effect of Dutch summer weather on tourists is limited can also be demonstrated by data on total tourist numbers (domestic and abroad) for the period 1969-1995. This data suggests that a summer which is 1ºC warmer than average, increases domestic holidays in the same year by 4.7% (standard deviation: 2.2%), and increases foreign holidays in the following year by 3.1% (standard deviation: 1.5%) (Chapter 2). There are two possible explanations for this. Firstly, Dutch tourist may expect a bad summer to follow a good one. This mistrust is unwarranted, as the correlation coefficient between successive summers (in De Bilt) is a positive 0.52. CBS (1993) finds that snowfall in popular ski-resorts in this season is a good predictor for next season's visitor numbers. An alternative explanation is that the money saved on a cheap domestic holiday for this year is spent on a more expensive foreign trip next year.

While tourist activities in summer are not very sensitive to weather conditions, winter tourists are. They have just one factor that fully corresponds in both years: tourists who go for warmer weather during the winter season (factor 2 on sunbathing). A striking result is the change in the first factor. In 1988, the first factor is dominated by visiting a monument or a museum. In 1992, the first factor contains the same indicators, but is added by travelling in public transport and visiting a theatre. This means that travelling in winter is becoming more packed, stuffing more and more activities into a holiday. Further, remark that a number of factors appear both in 1988 and 1992, but with different priorities. For instance:

- Factor 3 in 1988 resembles factor 5 in 1992 (visiting a sauna, swimming).
- Factor 4 in 1988 resembles factor 8 in 1992 (out in the city: visiting a restaurant or café).
- Factor 5 in 1988 (tennis, midget, golf) almost resembles factor 7 in 1992 (tennis, golf).
- Factor 7 in 1988 resembles factor 4 in 1992 (sailing, surfing).

Table 3.8 Component matrix: choice of Dutch summer tourists.

	1988									1992									
Factor	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9	10
Car driving			-x		x							-x							
Cycling					-x														
Other transport			x									x							
Boating																			
Walking									x									x	
Luna park				x									x						
Zoo				x									x						
Cultural		x									x								
Monument		x									x								
Museum		x									x								
Restaurant																			
Theatre																			x
Café			x													x			
Sun	x									x									
Beach	x									x									
Sauna								x											x
Swimming	x									x									
Sailing						x									x				
Surfing						x									x				
Fishing																			
Tennis							x							x					
Midget														x					
Golf								x											x
Horse riding				x													x		
Skiing							x									x			
% explained	9.0	7.5	6.0	5.3	4.7	4.5	4.3	4.2	4.1	8.5	7.4	5.9	5.5	4.7	4.5	4.4	4.1	4.1	4.1

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalisation. Dominating factors are displayed as “x”, negative dominance is displayed as “-x”.

Table 3.9 Component matrix: choice of Dutch winter *tourists and some factors for all tourists.*

	1988										1992										All tourists 1992		
Factor	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	2	4	7
Car driving						x							x										
Cycling								x											-x				
Other transport											x												
Boating																							
Walking						-x														x			
Luna park										x												x	
Zoo																						x	
Cultural																							
Monument	x										x										x		
Museum	x										x										x		
Restaurant				x														x					
Theatre											x												
Café				x														x					
Sun		x										x											
Beach		x										x											
Sauna			x												x								x
Swimming			x												x								
Sailing							x							x									
Surfing							x							x									
Fishing									x														
Tennis					x												x						x
Midget					x																		
Golf					x												x						
Horse riding										x						x							
Skiing																			x		-x		
% explained	9.7	7.1	5.9	5.2	4.8	4.8	4.7	4.6	4.4	4.0	9.6	8.2	5.8	5.4	5.0	4.8	4.5	4.4	4.3	4.1	7.8	5.2	4.3

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalisation. Dominating factors are displayed as “x”, negative dominance is displayed as “-x”.

Finally, factor 6 (driving the car and no walking), factor 8 (cycling), factor 9 (fishing) and factor 10 (visiting a luna park, horse riding) in 1988 have been interchanged by factor 3 (car driving), factor 6 (horse riding), factor 9 (no cycling, skiing) and factor 10 (walking). Further, skiing is excluded from the factors for winter tourists in 1988, while it is present again in 1992. Indicating that in a warmer winter, cycling or fishing seems to be an alternative for skiing. However, in spite of a mild Dutch winter, the number of skiers was even higher: 3.7% in 1988, while there are 3.4% skiers in 1992.

3.4.2 Sensitivity of Dutch tourist activities to other factors

To obtain the sensitivity of the choice for activity during a holiday to climate (change) and other variables, the calculated factors of the last subsection can be used for a regression analysis on the total data set. As a first step in a regression analysis, an appropriate dependent variable needs to be chosen. There are many possibilities for that (Hsieh and O'Leary, 1997; Mendelsohn and Markowski, 1999):

- activities during a holiday;
- destination (home/abroad, hot/warm/medium/cold);
- duration of the holiday;
- number of visits; or
- cost of stay.

Of these, the first variable seems most meaningful and in that way a logical link to the last subsection is established. Such an analysis this gives the driving factors behind tourist activities during a holiday, where the sensitivity to climate change can be studied as well.

As a second step in a regression analysis, consider the descriptive variables to be included. As before the CVO data set is used altered with information from other sources, to study the sensitivity of tourist activities to climate. Thereupon, the square of temperature is included in the variable list in spite of its high correlation with temperature. The purpose is to find a significant estimate for both coefficients, so that the optimal temperature can be derived. It is intuitive to expect that tourists prefer intermediate temperatures above high or low temperatures. Empirical evidence is sought for to verify that intuition.

Given the available data it is possible to estimate the following ordinary linear regression model:

$$\begin{aligned}\text{Factor } i = {} & \beta_0 + \beta_1 TQ + \beta_2 TQ^2 + \beta_3 PRECIP + \beta_4 SUN + \beta_5 PDAY + \beta_6 DIST + \\ & \beta_7 DUR + \beta_8 PERSON + \beta_9 INCOME + \beta_{10} AGE + \text{error}\end{aligned} \tag{4.1}$$

Initially, this equation is estimated for 9 to 10 different factors, for summer, winter and all tourists, and for 1988 and 1992; in total, 57 regressions (Lise and Tol, 1999). In order to have a manageable number of regression, only those cases where β_1 and β_2 are statistically significant are presented. Table 3.10 shows the results, where the adjusted R^2 is quite low in each case. However, when the t-statistics are significant, the result can still be treated meaningfully.

Table 3.10 Regression results for the micro model for choice of holiday activity in 1992.[a]

	Winter tourists				All tourists		
	Factor 3	Factor 4	Factor 6	Factor 8	Factor 2	Factor 4	Factor 7
Meaning of factor	Car driving	Sailing, surfing	Horse riding	Outing in city	Sight-seeing, no skiing	Visit atttraction	Tennis, sauna
Constant	-3.3	-2.1	-1.8	-1.4	-5.7	-1.4	0.60
	(0.6)	(0.6)	(0.7)	(0.7)	(0.4)	(0.4)	(0.36)
TQ	0.12	0.059	0.058	0.042	0.19	0.035	0.023
	(0.02)	(0.018)	(0.020)	(0.020)	(0.01)	(0.011)	(0.010)
TQ^2	-0.0025	-0.0028	-0.0028	-0.0025	-0.0037	-0.00088	-0.0011
	(0.0007)	(0.0008)	(0.0009)	(0.0009)	(0.0004)	(0.00036)	(0.0003)
PRECIP			-0.057	-0.10	-0.12	0.10	
			(0.032)	(0.03)	(0.02)	(0.01)	
SUN	-0.12				-0.17		
	(0.02)				(0.02)		
PDAY	-0.0014			0.0026			0.00085
	(0.0004)			(0.0004)			(0.00024)
DIST		0.00028	0.00017	9.6E-05	5.60E-05		
		(0.00002)	(0.00003)	(2.7E-05)	(1.7E-05)		
DUR					0.021	0.014	0.0077
					(0.002)	(0.002)	(0.0024)
PERSON	-0.016				-0.013		0.0073
	(0.003)				(0.002)		(0.0025)
INCOME	4.3E-06				4.2E-06		-2.2E-06
	(1.8E-06)				(1.0E-06)		(1.1E-06)
AGE		-0.0050	-0.0058	-0.0040	0.0079	-0.0081	-0.0075
		(0.0013)	(0.0014)	(0.0014)	(0.0007)	(0.0008)	(0.0008)
Optimal *TQ*	24.1	10.5	10.4	8.6	24.8	20.1	10.2
	(5.1)	(3.0)	(3.5)	(3.6)	(2.1)	(7.1)	(3.8)
# Observations	1310	1310	1310	1310	4301	4301	4301
Adjusted R^2	0.08	0.12	0.04	0.04	0.13	0.06	0.03

[a] Regression on holiday activity as expressed by a factor. Standard deviations are given in brackets.

Equation 4.1 contains 3 climatic variables and 6 socio-economic variables. Let use first interpret the signs of the socio-economic variables. The coefficient for *AGE* is generally negative, except for sight-seeing. This indicates that all considered activities are preferred by younger people except for sight-seeing. While this pattern holds for the 57 regressions, mentioned above, it is also confirmed by Table 3.10. The positive signs for *DIST* and *DUR* indicate that a tourists who go further away for a longer time undertake more activities. The significant estimates for *PDAY* indicate that the daily expenditure is low for car-travellers and high for travellers who go out in the city and play tennis/use the sauna.

Now the chapter will focus on the climate variables. While the optimal temperatures are almost constant for the country-wise tourists flows, more variation is found when tourist activities are considered; cf. Table 3.10. Clearly, sport activities (sailing, surfing, horse riding and tennis) and outing in city are preferably undertaken in cold weather ($TQ^{opt} \approx 10°\mathrm{C}$). Attraction park visitors prefer a temperature around 20°C, while the optimal temperature for car driving (24°C) and sight-seeing (25°C) are exceptionally high. It is not clear why this should be the case. Most activities are more likely to take place with low amounts of precipitation, except for visiting a monument or a museum. The negative sign for the number of sun hours for car driving and sight-seeing is not expected.

3.5 Discussion and conclusions

The analysis of this chapter leads to the conclusion that climate is an important consideration for the choice of tourist destination. This should not surprise anyone. However, this chapter finds that climate matters in a *regular* way that can be *quantified*. Yet, only the broad patterns are regular, not the details. This chapter finds small shifts in behaviour of Dutch tourists from 1988 to 1992. These may be partly due to random fluctuations, and partly caused by the different weather patterns in The Netherlands in these two years. The importance of age and income variables suggests that there are trends in the behaviour of Dutch tourists, an issue the data set of this chapter does not allow to explore further. The factor and regression analysis also reveal that different dominant holiday activities imply different preferences for holiday climates. For some activities, tourists are indifferent to climatic conditions. Younger and richer people do different things during their vacations than do older and poorer tourists. This suggests that preferences for climates at tourist destinations shift over time.

The macro-data do not reveal such linkages. Instead, this chapter finds that an average temperature of about 21ºC is the ideal for the large bulk of international tourists. This preference varies between 20.3ºC for Americans and 22.4ºC for French, but this difference is insignificant. Tourists' preferences are largely independent of the tourists' origin climate. It may be that the trends suggested by the micro-analysis of Dutch tourists are too slow to show up in the macro-analysis. Or, the macro-analysis may be too crude to detect subtle trends. In any case, the found ideal temperature of 21ºC is unlikely to be constant between tourists of all ages.

The study of the link between the macro and micro approach is an area for further research. Another item on the future research agenda is to conduct similar on other countries or more detailed studies on the UK and The Netherlands to see whether the discovered macro regularity can be confirmed. In that process, other relevant climate indicators can be included as well to get a more complete picture on the sensitivity of tourist demand to climate change. The impact of these changes can surely also alter tourism demand.

Besides, this study suggests that people's preferred vacation activities are likely to be largely independent of climate. Instead, people probably purchase a holiday climate that would suit their plans. A gradual warming would thus induce tourists to seek different holiday destinations. When the supply of tourist facilities (hotels, transportation, etc.) lags behind changes in demand, a change in tourist behaviour may be observed. This would imply a welfare loss for the tourist. Tourists could, of course, choose to travel earlier or later in the season. However, vacation periods are often tied to seasons of the home climate, national and school holidays, and agreements at work. Changes in economic structure, demography, and air condition could loosen this tie. Whereas tourist can readily change their behaviour if climate changes, suppliers of tourism services cannot always. Tour operators can rapidly change their product. International hotel chains are also adaptable, but their property would change value with climate. Local tourist providers are likely to be affected most, seeing the attractiveness of their region to tourists change beyond control.

4. Water Consumption

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4.1 Introduction

This chapter presents a brief overview of supply and demand of water in The Netherlands, with special reference to water companies and drinking water. We first present some information on water supply (Section 4.2). Section 4.3 goes into the demand for water. Section 4.4-4.9 discuss impacts of weather variability on water demand.

4.2 A brief overview of supply of water in The Netherlands

Table 4.1 shows that about 5 per cent (~ 5,000 m^3 per year) of all water that 'enters' the Dutch territory is somehow used. Most of the latter (about 80 per cent) is used directly in agriculture and industries. About 1,250 million m^3 of water is used by the water companies, for production of water suitable for drinking.

Table 4.1 Water balance of The Netherlands.

Balance item	On average (million m^3)	Dry year (1976) (million m^3)
Precipitation	30,100	20,800
River Rhine	69,000	41,500
River Meuse	8,400	3,500
Other rivers	3,000	1,500
Total input	*110,500*	*67,300*
Evapotranspiration	19,500	20,500
Various uses	5,000	6,000
Discharge into the North Sea	86,000	40,800
Total output	*110,500*	*67,300*

Source: TNO (1986).

The main resources of water (suitable for drinking[9]) for the Dutch water companies are the river Rhine, the river Meuse and ground water. Water of both rivers is directly puri-

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fied (e.g., $FeCl_3$ coagulation, filtering, oxidation (ozonisation), decalcification, sand bed filtration). Some water of the river Rhine is, after a pre-purification, also used for recharging ground water resources, in particular the resources in the dunes. The fresh water aquifers in the dune area along the shore of The Netherlands constitute historically the first modern resource of water. For the Western part of The Netherlands (including the cities of Amsterdam and The Hague) these aquifers are still a major resource.

By Dutch law (*Waterleidingwet*), the responsibility for security of supply of water (both quantity and quality) is in the hands of the Dutch National Government. The management of this responsibility is by law in the hands of the water supply companies (*Waterleidingbedrijven)*. These companies are technically private companies, but they have been owned by provinces and municipalities since the beginning of the twentieth century. Through these companies, municipalities (and provinces) managed their responsibilities for public health. In 1940 there were about 210 companies. Since then, this number declined sharply through a process of merger. Nowadays (1998) there are about 80 water companies.

Currently, the *Waterleidingwet*, is evaluated. The start of this process was a scenario analysis of the water industry, involving consultation of stakeholders in the industry (Twijnstra Gudde, 1997). The objective of this investigation was to examine different types institutional structures for the water industry. The background of this project is the trend in public policy and administration to increase efficiencies by incorporating market incentives in the system. In addition, other developments (e.g. in technology of water production and distribution) warranted an evaluation of institutional structures around the production of water for drinking purposes. One of the issues being discussed is how the supply of drinking water could be institutionally connected with the organisations that run sewage systems and sewage works. In contrast to other countries (e.g. the UK), in The Netherlands the organisation of the supply of drinking water is quite remote from the organisations that run the sewage works.

In the Twijnstra Gudde report (1997), we did not find any reference to climate change or change in weather variability. Apparently, for the organisation of water production and water distribution, climate is not an issue. This conclusion does not hold for the strategies to manage water resources. This area is the responsibility of the national government and beyond the scope of the water companies. Indeed, the integrated water planners at the national scale are well aware of climate change (Van der Grijp and Olsthoorn, 2000).

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[9] As opposed to water suitable for cleaning purposes only. Historically, in the 19th century new water supply companies (initially private companies that were given a concession by municipalities) evolved from concerns of public health. These companies produced water suitable – according to public health criteria – for human consumption. For some time (but not any more), these companies existed together with companies that supplied water for purposes such as cleaning. In recent years, there has been a tendency reintroduce water of different qualities for domestic use (grey water). (Water companies have long supplied ‘industrial quality’ water to industries). Grey water can be produced from water resources at less cost, using less precious water resources. Especially in new town developments, the costs of the required double piping system are compensated by the gains of lower production costs.

Obviously, weather variability affects supply of water, if the temporal scale of the weather variations is larger than the response time of the production system (buffer capacity). This large time-scale weather variability (drought) is beyond the scope of the WISE study. Nevertheless, we may observe that the water companies that rely on the river Meuse as resource, seem the most vulnerably, since the discharge of this rain-fed river is more sensitive to periods of drought than the river Rhine[10] (van Deursen *et al.*, 1998). Problems - when demands from navigation, agriculture, industry, water companies and ecological demands exceed supply - arise when the discharge of the river Meuse drops under 50 m^3/s, as compared to 230 m^3/s on average.

4.3 Breakdown of demand for water

This section presents data on the break down of water consumption in The Netherlands. The data refer only to the water that is supplied by the water companies.

Table 4.2 presents figures of the overall demand for water by all Dutch water companies. Supply to the domestic sector accounts for 56 per cent of all supply on an annual basis.

Table 4.2 Breakdown of demand for water supplied by water supply companies in The Netherlands. 1995.

Sector	Million m^3	Per cent
Domestic sector (< 300 m^3/y)	726	56.2
Institutional sector (300-10,000 m^3/y)	260	20.2
Large consumers (> 10,000 m^3/y)	186	14.4
Other water (not suitable for drinking)	62	4.3
Leakage	56	4.8
Total production	1290	100.0

Source: VEWIN, as cited by Twijnstra Gudde, 1997.

Table 4.3 shows the results of two consecutive surveys among 2,000 Dutch households to find a break down of water consumption (Achttienribbe, 1996) in the domestic sector. The decrease in the consumption over the period 1992-1995 is significant. The decrease is explained as the result of the policies of the Drinking water companies to promote water conservation (a stated 11.1. litre/year) which has been off set by an ‘autonomous’ increase of 7.1 litre per year (Achttienribbe, 1996). The latter is the result of an increase in shower frequency and a 10% increase in the use of washing machines. Most of the water conservation is the result of shorter showers, the spread of the use of water conserving shower heads, and an increase in the use of water conserving type of toilet flushing systems.

[10] The discharges of the Meuse river (on the border of the Netherlands) range between 1300% and 0% of the average (230 m^3/s), while the discharges of the river Rhine range from 600% to 0.3% of the mean discharge (2200 m^3/s).

Table 4.3 Per capita water consumption in The Netherlands.

Purpose of water consumption	1992 (litre per day)	1995 (litre per day)
Bath	8.6	9.0
Shower	42.5	38.3
Washing stand	3.7	4.2
Toilet flushing	42.3	39.0
Cleaning textile (by hand)	2.5	2.1
Cleaning textile (washing machine)	22.5	25.5
Dish washing (by hand)	4.9	4.9
Dish washing machine	0.9	0.9
Food preparing	2.0	2.0
Other	8.2	8.2
Total	138.1	134.1

Source: Achttienribbe, 1996.

Table 4.4 gives a breakdown of water consumption by Amsterdamers. In total, on average, an Amsterdamer uses 150 litre daily, according to *Gemeente Waterleidingen Amsterdam* in public relations brochures.

Table 4.4 Structure of average water demand of Amsterdam consumers

Purpose of water consumption	Litre daily
Shower, bath, washing	54
Toilet flushing	46
Cleaning textile	27
Kitchen use	13
Spraying gardens and car washing	10
Total	150

It is unknown why city dwellers use more water than individuals elsewhere.

4.4 Possible impacts of changing weather variability on water supply companies

How might a change in weather variability affect the water supply system? We may distinguish two types of effects. First, weather variability may influence peak demand. This would have an impact on the requirements set to the capacity of the distribution system. Secondly, weather variability might change demand on a larger time scale, i.e. annual water consumption. For instance, in a different climate, it is not unlikely that the consumption pattern would be different from the current consumption.

There are no indications that conceivable changes in weather variability would have impact on instantaneous peak demand. Water supply engineers distinguish three main elements in the distribution system. The main piping system (from the production facility to the urban area, an intermediate piping system and a local piping system, supplying domestic users). In engineering guidelines, weather variability is not an issue at all. Experts in water supply planning (Vreeburg, personal communication, 1999; van Duist, personal communication, 1999) are not particularly worried about changing weather variability affecting the temporal pattern of demand for water. In The Netherlands, peak demand tends to be associated to TV events such as World Cup soccer matches, rather than to demand for, say, spraying gardens during dry spells in summer.

Changes in annual demand would have impacts in the long term, and, if important would have to be considered in long-term planning of water companies. For the long term planning of water supply systems water supply companies use scenarios for water consumption (van Duist, 1996). In these models, future water consumption is represented as the product of the future number of households and the average number of person per household, and water consumption per household of a given composition. Planning of future demand and production capacity of the companies is co-ordinated by means of a strategic plan of the Dutch national government. National policies are written down in the *Beleidsplan Drink- en Industriewater-voorziening* (policy plan on the supply of drinking water and water for the manufacturing sector). Part of this planning is the construction of forecasts of water demand (made by the VEWIN, the association of water supply companies, to be endorsed by the Ministry of Housing, Spatial Planning and Environment (VROM)). Conservation of water is an import instrument for long term planning of water supply (as well as an environmental goal in itself). Table 4.3 shows that so far this proved to be a viable and effective policy option. There are several technical options for conserving water in toilet flushing, showerheads, dish washing machines, washing machines and so on. The estimate is that per capita consumption can be reduced to slightly over 100 litres per day, compared to about 135 litre per day in 1995. Planners expect that the effects of demographic developments are largely off-set by a further penetration of appliances that conserve water (van Duist, personal communication, 1999).

From this analysis of developments and expert opinions we conclude that within the industry the prospect of climate change did not prompt questions on its effects with respect to demand for water in relation with short term-the weather variability. Whether this attitude is to be supported or to be questioned, is the objective of the analysis in the next sections.

4.5 Approach

A major decision for analysis is the temporal scale. Most WISE analysis is on a monthly scale. In the case of drinking water consumption, we investigate matters on a daily, weekly and monthly scale, to test the appropriate temporal scale. For instance, one might expect that the use of drinking water for gardening is decided upon in time steps of a few days, rather than months. People may well have a weekly cycle in their behaviour (e.g., washing, gardening), which is removed by aggregating the seven days of the week, and blurred by aggregating to months.

In the province of North Holland, there are two companies that produce drinking water. The first company is *Gemeentewaterleidingen Amsterdam.* This company supplies water to Amsterdam and to some of its surrounding municipalities. The company is since 1896 owned by the municipality of Amsterdam. *Waterleidingbedrijf Noord-Holland* is the second company – owned by the province of North-Holland – supplying water to the rest of the province. *Waterleidingbedrijf Noord-Holland* provided daily water production figures for the period 1981-1997, for four regions (*Texel, 't Gooi, Haarlemmermeer* and the region North of the *Noordzeekanaal: Noordkop*). *Gemeentewaterleidingen Amsterdam* provided similar data for the period 1987-1997. Actually, these data relate to the supply of drinking water in *Amsterdam,* and its adjacent municipalities *Diemen, Muiden, Amstelveen* and *Ouder-Amstel*. Water consumption is measured in cubic metres per day. For the monthly and weekly analysis, *average* daily water consumption was used. Tables 4.5 to 4.7 display some characteristics of the data.

Table 4.5 Average daily water consumption (mean) and the coefficient of variation (CoV) for the five areas and three time-scales of analysis.

	Mean[a]	Cost[b]	Daily CoV	Weekly CoV	Monthly CoV
Amsterdam	194	582	6.1%	4.3%	3.7%
Noordkop	154	462	11.0%	9.8%	9.3%
Haarlemmermeer	30	90	42.6%	41.4%	41.3%
’t Gooi	24	72	24.9%	24.7%	22.5%
Texel	4	12	33.1%	32.4%	30.8%

[a] Thousands of cubic metres per day.
[b] Thousands of Dutch guilders per day. The unit price is DGl. 3/m^3.

Table 4.6 Some characteristics of the analysed areas.

	Area[a]	Rural[b]	Population[c]	Density[d]	Consumption[e]
Amsterdam	31.5	0.62	832	26.4	0.23
Noordkop	225.6	0.89	934	3.7	0.16
Haarlemmermeer	45.6	0.82	402	8.8	0.07
’t Gooi	18.2	0.71	243	13.3	0.10
Texel	46.3	0.98	13	0.3	0.31

[a] 1000 ha; including water.
[b] Percentage of dryland.
[c] 1000 people.
[d] Number of people per hectare, excluding rural areas.
[e] Cubic meter per person per day.

Table 4.7 Average daily temperature and precipitation and their coefficient of variation (CoV) for the three time-scales of analysis.

	Mean	Daily CoV	Weekly CoV	Monthly CoV
Temperature	9.84[a]	65%	62%	58%
Precipitation	1.67[b]	213%	123%	80%

[a] Degrees centigrade, 24-hour average.
[b] Millimetres per day.

From KNMI (1982ff, 1991, 1992ff) and NOAA (http://ingrid.ldgo.columbia.edu), we obtained daily meteorological data for weather stations in and near this province. We used daily average temperature and daily precipitation. The data stations are *De Bilt* (in *’t Gooi*) – for temperature and precipitation – and *De Kooy* (near *Den Helder,* the northern tip of the mainland of the province) for precipitation. Temperature is measured in degree Celsius. Data are on the 24-hour average. Again, monthly and weekly averages of daily data were used. Precipitation is measured in millimetres per day. We used the average of *De Bilt* and *De Kooy*. Table 4.8 displays some characteristics of the data.

Models were specified as follows. The initial model includes a number of lags of the explanatory and dependent variables, a constant, and a trend. That is,

$$W_t = C + \beta t + \sum_{s=1}^{r} \rho_s W_{t-s} + \sum_{s=0}^{k} \kappa_s T_{t-s} + \sum_{s=0}^{l} \lambda_s T_{t-s}^2 + \sum_{s=0}^{a} \alpha_s P_{t-s} + \sum_{s=0}^{d} \delta_s P_{t-s}^2 + \varepsilon_t \qquad (4.1)$$

where *W* denotes water consumption, *t* time, *T* temperature, and *P* precipitation. Noise is denoted by ε; noise is assumed to be indepently and identically distibuted. The other Greek letters are estimated parameters. Constant *C* is also estimated; it may vary between months and days with dummies. Insignificant parameters were subsequently removed, while checking for joint significance.

4.6 Results of the daily analysis

Tables 4.8, 4.9, and 4.10 display the results for days, weeks and months for the five areas in North-Holland. Daily water consumption shows a significant upward trend for all areas. This trend results from a growing population, which offset the decrease in water consumption per head. Current water consumption depends on water consumption in the previous two to four days. There is a significant pattern of water consumption over the days of the week. In all areas, water consumption is highest on Mondays (when most laundry is done). Note that this pattern gradually disappears over time, an effect not considered in this analysis. At Texel, water consumption is significantly higher in summer due to the large influx of tourists. For other areas, the seasonal pattern is wholly attributed to temperature and precipitation, because we do not have data on actual numbers of inhabitants at the appropriate time scales. The explained fraction of variance is reasonable to good.

Water consumption depends on today's and yesterday's temperature and temperature squared. In Amsterdam, the temperature of the day before yesterday also matters. Temperature squared is not sufficient to capture all non-linearity. Dummies for warm (above 20°C) and hot (above 25°C) days are significant. Figure 4.1 displays the effect of high temperature on the water consumption of that day, relative to a daily temperature of 17°C (about the average 24-hour temperature in summer). Despite the squared temperature, the response is almost linear, except for the effect of the dummies.[11] Clearly, high temperature increases water consumption with several percent. This number can be explained with a look at Tables 4.3 and 4.4, the structure of average water demand. Showers consume about 20% of total demand. An extra shower on a hot day thus substantially increases water demand. Gardening consumes about 1/15 of average water demand in Amsterdam, where there are relatively few and small gardens. Average water consumption is based on the whole year, while gardening is concentrated in summer.

The pattern of dependence on precipitation is mixed. Water consumption in the Noordkop is influenced by precipitation and precipitation squared four days before, whereas

[11] Water consumption is minimum below freezing point, at a temperature close to the minimum of the observed temperatures in the record.

water consumption in the Haarlemmermeer only depends on precipitation on the current day.

Figure 4.2 displays the effect of low precipitation on the water consumption of that day. The influence of precipitation is two orders of magnitude smaller than that of temperature; it is measures in tenths of percents rather than in tens of percents. Again, the response is almost linear.[12]

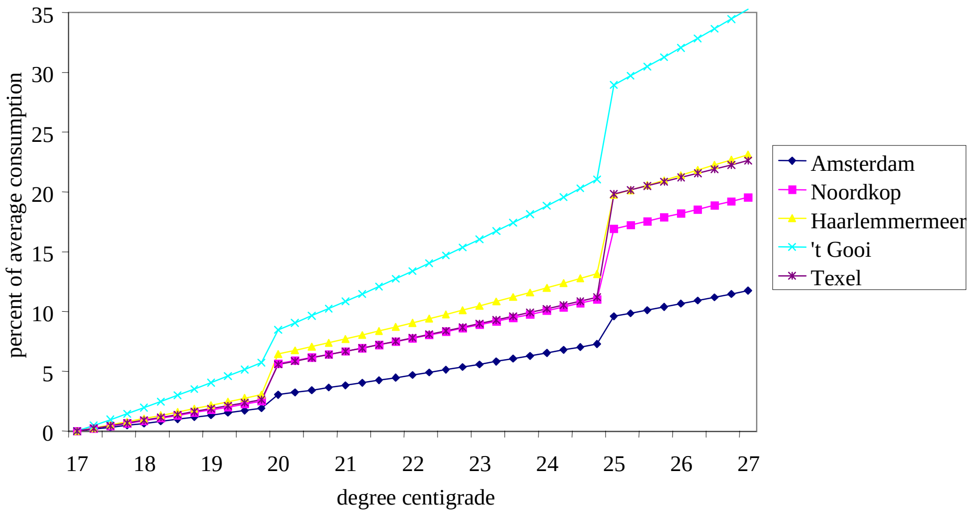

Figure 4.1 Daily water consumption as a function of daily temperature. Water consumption is given in deviation from typical water consumption at a day of 17°C. Only current effects are considered, that is, lag patterns are ignored.

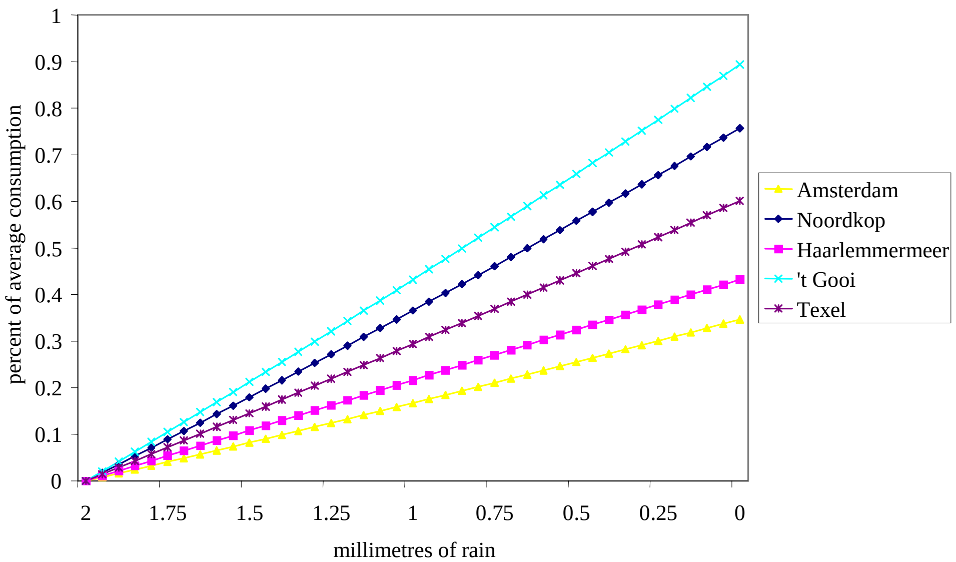

Figure 4.2 Daily water consumption as a function of daily precipitation. Water consumption is given in deviation from typical water consumption at a day with 2 mm of rain. Only current effects are considered, that is, lag patterns are ignored.

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[12] Water consumption is minimum at negative precipitation.

Table 4.8 Regression results for daily water consumption.

Variable	A'dam	Noordkop	H'meer	't Gooi	Texel
C	-212697.07	-1048508.41	-271137.21	-119927.68	-17650.78
	(62445.40)	(65333.34)	(17950.35)	(14557.95)	(1781.68)
TUE[a]	-11498.22	-14033.56	-3389.95	-3009.69	127.84
	(483.41)	(415.46)	(124.84)	(97.38)	(13.21)
WED[a]	-10450.05	-10380.07	-2664.75	-2247.97	67.03
	(535.67)	(401.23)	(120.77)	(99.90)	(13.13)
THU[a]	-12994.10	-12401.14	-2809.33	-2451.56	94.37
	(383.58)	(376.66)	(116.36)	(93.97)	(13.15)
FRI[a]	-11665.31	-10811.43	-2792.82	-2087.45	144.45
	(400.94)	(344.40)	(105.49)	(92.82)	(13.13)
SAT[a]	-25491.78	-15703.19	-4180.86	-3335.38	188.55
	(396.09)	(343.02)	(105.55)	(91.15)	(13.13)
SUN[a]	-16744.75	-20747.83	-5999.80	-2675.10	146.47
	(419.19)	(328.07)	(100.00)	(91.87)	(13.13)
JUN[b]					59.98
					(14.67)
JUL[b]					281.77
					(19.38)
AUG[b]					138.18
					(19.78)
YEAR[c]	134.22	550.11	140.29	62.51	9.01
	(31.65)	(33.54)	(9.11)	(7.37)	(0.90)
T	-478.83	-121.27	-88.83	-128.35	-3.35
	(78.75)	(72.04)	(21.88)	(20.55)	(3.00)
T(-1)	486.11	253.34	69.45	141.91	9.10
	(108.60)	(70.73)	(21.38)	(20.07)	(2.95)
T(-2)	-190.33				
	(77.25)				
T^2	49.56	41.50	11.42	17.21	1.08
	(3.66)	(3.39)	(1.03)	(0.97)	(0.14)
$T^2(-1)$	-42.08	-44.60	-9.84	-17.16	-0.83
	(4.74)	(3.14)	(0.95)	(0.90)	(0.13)
$T^2(-2)$	6.41				
	(3.49)				
P	-360.52	-623.43	-64.55	-115.55	-11.96
	(67.68)	(54.00)	(7.49)	(14.71)	(2.23)
P(-1)	205.80	200.34			-3.09
	(67.99)	(56.03)			(1.11)
P(-2)		91.00			4.04
		(55.81)			(1.07)
P(-3)		119.49			
		(54.19)			
P^2	11.99	19.88		3.64	0.26
	(3.78)	(2.88)		(0.81)	(0.12)
$P^2(-1)$	-8.36	-4.61			
	(3.79)	(2.91)			
$P^2(-2)$		-4.92			
		(2.90)			
$P^2(-3)$		-6.05			
		(2.88)			

Table 4.8 Regression results for daily water consumption (continued).

Variable	A'dam	Noordkop	H'meer	't Gooi	Texel
W(-1)	0.59	0.42	0.47	0.63	0.66
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
W(-2)	0.08	0.10	0.19	0.11	0.21
	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
W(-3)	0.11	0.16	0.11	0.11	
	(0.01)	(0.01)	(0.01)	(0.01)	
W(-4)		0.10	0.06	0.05	
		(0.01)	(0.01)	(0.01)	
WARM[d]	1830.86	4468.93	921.25	526.20	102.82
	(578.27)	(558.81)	(168.89)	(159.74)	(23.01)
HOT[d]	3985.73	8638.89	1850.41	1732.80	315.89
	(1968.39)	(2150.29)	(690.10)	(646.62)	(89.74)
1997[e]			7260.44		
			(365.98)		
Adj. R^2	0.77	0.85	0.97	0.90	0.95
N[f]	4015	6205	6188	6188	6207

[a] Daily dummies measure the deviation of average water consumption on that day from the average water consumption at the standard day (Monday).
[b] Monthly dummies measure the deviation of water consumption in that month from the average water consumption in standard months (Sep-May).
[c] Time trend.
[d] Warm and hot dummies measure the deviation of water consumption when temperatures exceed 20ºC and 25ºC.
[e] The 1997 dummy measures the deviation of water consumption from 1997 onwards in Haarlemmermeer due to a change in service area.
[f] Number of observations.

4.7 Results from the weekly analysis

Table 4.9 displays the results of the estimation at a weekly basis. Again, a significant upward trend is found. The lag pattern is simple. Water consumption depends on the consumption of last week, but not on the weeks before that. Temperature has a significant influence on water influence. Despite the quadratic terms, the response is almost linear in the relevant range; cf. Figure 4.3. A similar finding holds for precipitation; cf. Figure 4.4. As in the daily analysis, temperature is much more important than precipitation. The interpretation of these findings is similar to those of the daily analysis.

Table 4.9 Regression results for weekly water consumption.

Variable	A'dam	Noordkop	H'meer	't Gooi	Texel
C	-173754.92	-1218889.21	-511243.90	-475807.29	-22508.91
	(140224.06)	(132798.41)	(42307.95)	(58548.39)	(6015.18)
YEAR[a]	114.45	633.46	262.23	243.09	11.61
	(71.20)	(68.19)	(21.46)	(29.63)	(3.04)
T	-869.10	-94.73	-53.59	-35.13	
	(127.27)	(98.24)	(29.25)	(44.44)	
T(-1)	419.25	223.29			
	(128.36)	(98.27)			
T^2	77.37	45.57	11.79	18.91	2.79
	(6.03)	(4.81)	(1.67)	(2.55)	(0.22)
T^2(-1)	-47.18	-46.74	-7.38	-13.27	-1.16
	(6.37)	(4.80)	(1.10)	(1.71)	(0.23)
P	-373.59	-1079.14	-596.70	-185.35	-26.23
	(110.70)	(219.08)	(84.83)	(50.96)	(6.15)
P(-1)		220.79			
		(89.69)			
P^2		76.90	50.68		
		(27.16)	(10.58)		
W(-1)	0.73	0.73	0.65	0.68	0.80
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)
1997[b]			14849.20		
			(854.09)		
Adj. R^2	0.69	0.90	0.98	0.77	0.92
N[c]	571	883	883	883	883

[a] Time trend.
[b] The 1997 dummy measures the deviation of water consumption from 1997 onwards in Haarlemmermeer due to a change in service area.
[c] Number of observations.

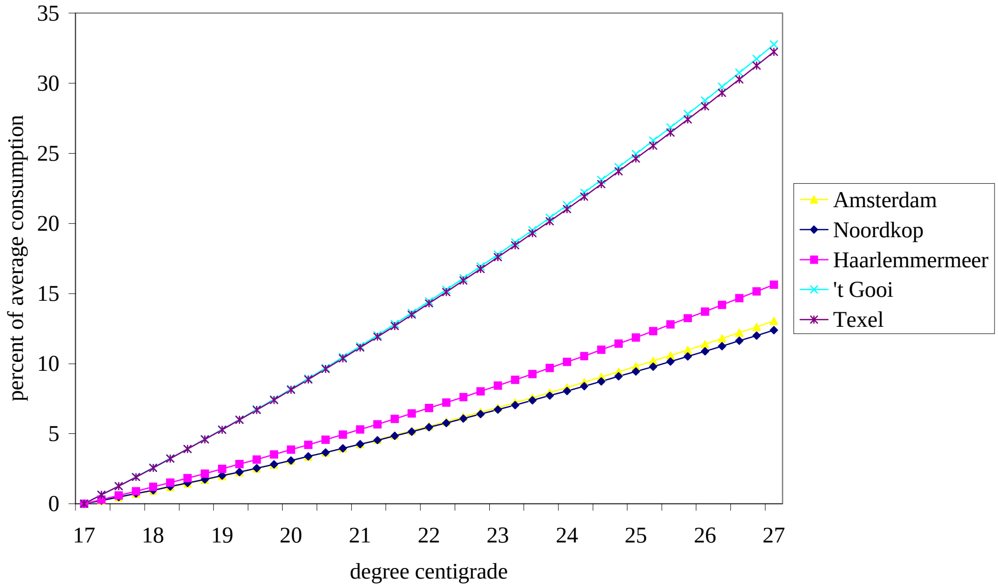

Figure 4.3 *Weekly water consumption as a function of weekly temperature. Water consumption is given in deviation from typical water consumption in a week of 17°C. Only current effects are considered, that is, lag patterns are ignored.*

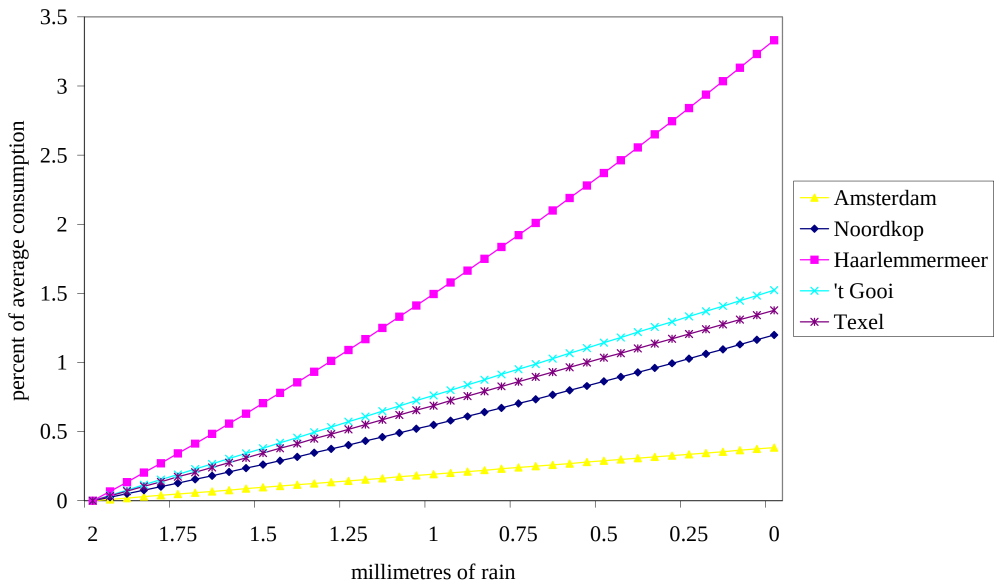

Figure 4.4 *Weekly water consumption as a function of weekly temperature. Water consumption is given in deviation from typical water consumption in a week of 14 mm of rain (2 mm per day). Only current effects are considered, that is, lag patterns are ignored.*

4.8 Results of the monthly analysis

Table 4.10 displays the results of the estimation at a monthly basis. Once more, a significant upward trend is found. The lag pattern is simple. Water consumption depends on the consumption of last months, but not on the months before that. Temperature has a significant influence on water influence. Despite the quadratic terms, the response is almost linear in the relevant range; cf. Figure 4.5 Precipitation is more non-linear, but the curvature is different for Amsterdam and Haarlemmermeer; cf. Figure 4.6. As in the daily and weekly analyses, temperature is much more important than precipitation. The interpretation of these results is the same as for those of the weekly and daily analysis.

Table 4.10 Regression results for monthly water consumption.

Variable	A'dam	Noordkop	H'meer	't Gooi	Texel
C	-1041425.54	-2572846.16	-934871.55	-439531.92	-141731.10
	(349852.46)	(378296.54)	(103487.40)	(103869.55)	(11893.05)
YEAR[a]	600.16	1333.51	482.62	224.44	72.70
	(178.49)	(194.82)	(52.35)	(52.65)	(5.98)
T		639.43	-107.44		-63.07
		(114.41)	(103.75)		(17.48)
T(-1)		-442.57	252.58		
		(114.72)	(104.38)		
T^2	25.91		10.33	18.72	12.01
	(4.55)		(5.20)	(2.30)	(0.88)
$T^2(-1)$			-13.20	-17.44	
			(5.09)	(2.37)	
P			-1735.20		
			(441.48)		
P(-1)			-1769.37		
			(439.94)		
P^2	-171.76		230.03		
	(86.60)		(84.56)		
$P^2(-1)$			257.06		
			(83.15)		
W(-1)	0.19	0.47	0.19	0.71	
	(0.08)	(0.07)	(0.05)	(0.05)	
1997[b]			31882.24		
			(2003.86)		
Adj. R^2	0.41	0.85	0.97	0.82	0.87
N[c]	131	203	203	203	204

[a] Time trend.
[b] The 1997 dummy measures the deviation of water consumption from 1997 onwards in Haarlemmermeer due to a change in service area.
[c] Number of observations.

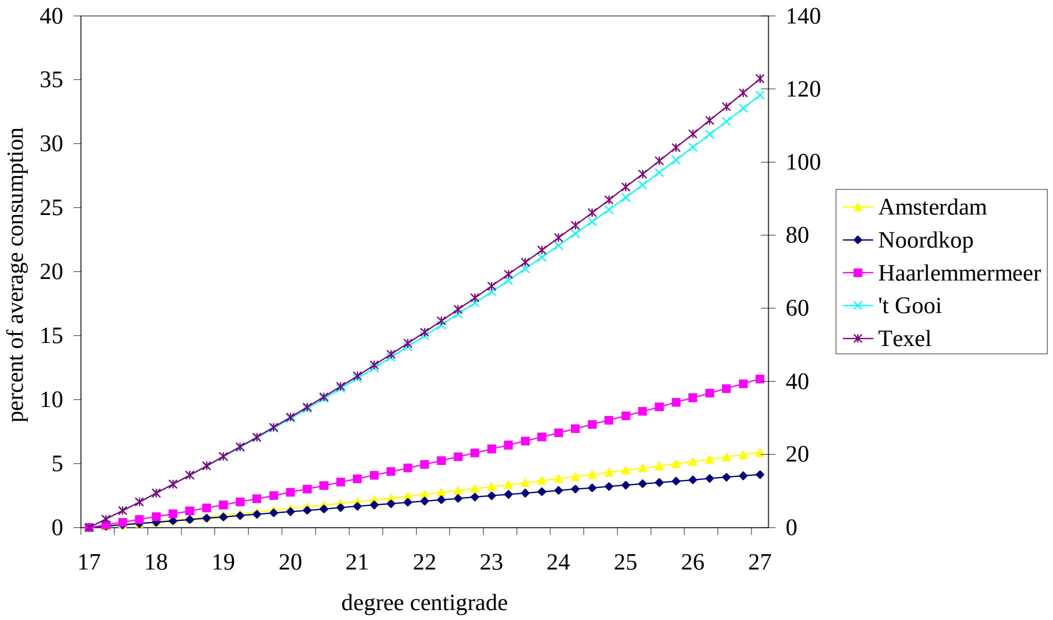

Figure 4.5 Monthly water consumption as a function of monthly temperature. Water consumption is given in deviation from typical water consumption in a month of 17°C. Only current effects are considered, that is, lag patterns are ignored.

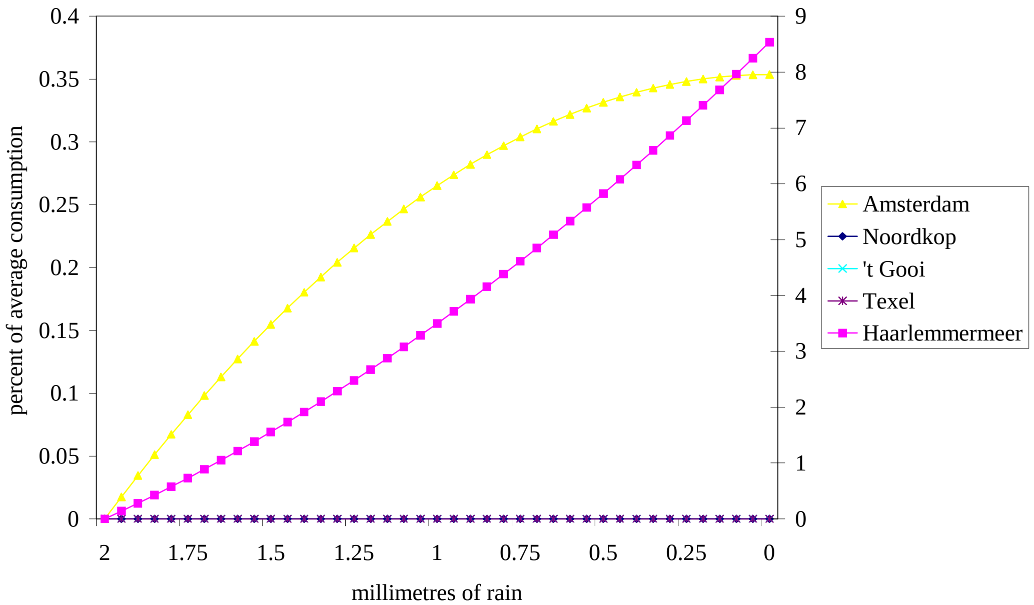

Figure 4.6 Monthly water consumption as a function of monthly temperature. Water consumption is given in deviation from typical water consumption in a month of 60 mm of rain (2 mm per day). Only current effects are considered, that is, lag patterns are ignored.

4.9 Comparison of results

Although Figure 4.1 to Figure 4.6 look deceptively linear, aggregation from the daily model to a weekly or monthly time-scale need not give the same results as the weekly or monthly model does. This is partly due to the quadratic terms, and partly due to the lag patterns. Table 4.11 demonstrates this for the daily and weekly models for Amsterdam. We compare a week that has an average temperature of 22°C to a week with an average temperature of 17°C (uniformly distributed over the days). The weekly model is insensitive to the distribution of temperatures over the week, but the daily model is not. We consider three scenarios: (a) seven days of 22°C; (b) three days of 27°C, one of 22°C and three of 17°C; and (c) three days of 17°C, one of 22°C, and three of 27°C. In the first scenario, the results of the daily and weekly models are almost identical. In the third scenario, the results do not differ significantly. In the second scenario, however, the outcomes of the daily and weekly models are significantly differently from one another.

Table 4.11 Comparison of the results of the daily and weekly models.[a]

	Additional water consumption		Difference with weekly model	
Week	75.2	(9.4)		
Day (uniform warm)	75.7	(4.9)	0.5	(10.6)
Day (first hot)	121.7	(9.0)	46.5	(13.0)
Day (first cool)	81.6	(7.0)	6.4	(11.7)

[a] Standard deviations are given in brackets.

Figure 4.7 further illustrates this effect. Here, we only consider uniform temperature distributions over the week, but we vary the deviation from the standard of 17°C. The outcome of the weekly model lies sometimes above the outcome of the daily model, and sometimes below; the results sometimes differ significantly, and sometimes do not.

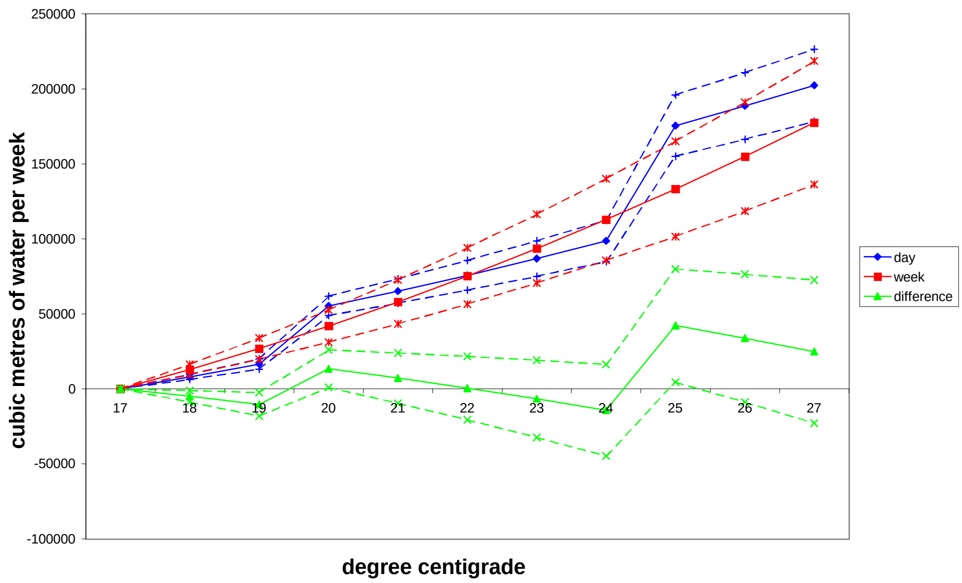

Figure 4.7 Average daily water consumption as a function of temperature according to the weekly and the daily model. Dashed lines denote the 95% confidence interval. Temperatures are assumed to be uniformly distributed over the week. For 22ºC, see Table 4.11

4.10 Adaptation

Adaptation can be looked at as the difference between the immediate reaction to a weather change and the long-term reaction. In the regression analyses in this chapter, this difference is determined by the parameters of the influence of past water consumption on current water consumption, as $1/(1-\Sigma\rho_s)$; cf. Equation (4.1). Table 4.12 displays the estimates for the five regions and three time-scales. In all cases, the long-term effect is greater than the short-term effect. That is, if the weather continues to be hot, water consumption increases. Figure 4.8 illustrates this for the daily Amsterdam model. The interpretation of this is that, on balance, consumers have a 'water reserve'. During incidentally hot weather, they need more water, part of which is purchased and part of which is taken from the 'reserve'. If the weather remains hot, however, the 'reserve' has to be replenished, so that more water is purchased.

Table 4.12 Ratios between equilibrium and immediate changes in water consumption.[a,b]

	Day		Week		month	
Amsterdam	4.63	(0.60)	3.65	(0.39)	1.24	(0.12)
Noordkop	4.48	(0.51)	3.74	(0.32)	1.89	(0.24)
Haarlemmermeer	5.79	(0.87)	2.82	(0.16)	1.23	(0.07)
't Gooi	11.12	(3.32)	3.13	(0.24)	3.47	(0.59)
Texel	7.56	(0.99)	5.04	(0.55)	1.00	(0.00)

[a] Standard deviations are given in brackets.
[b] See equation (4.1).

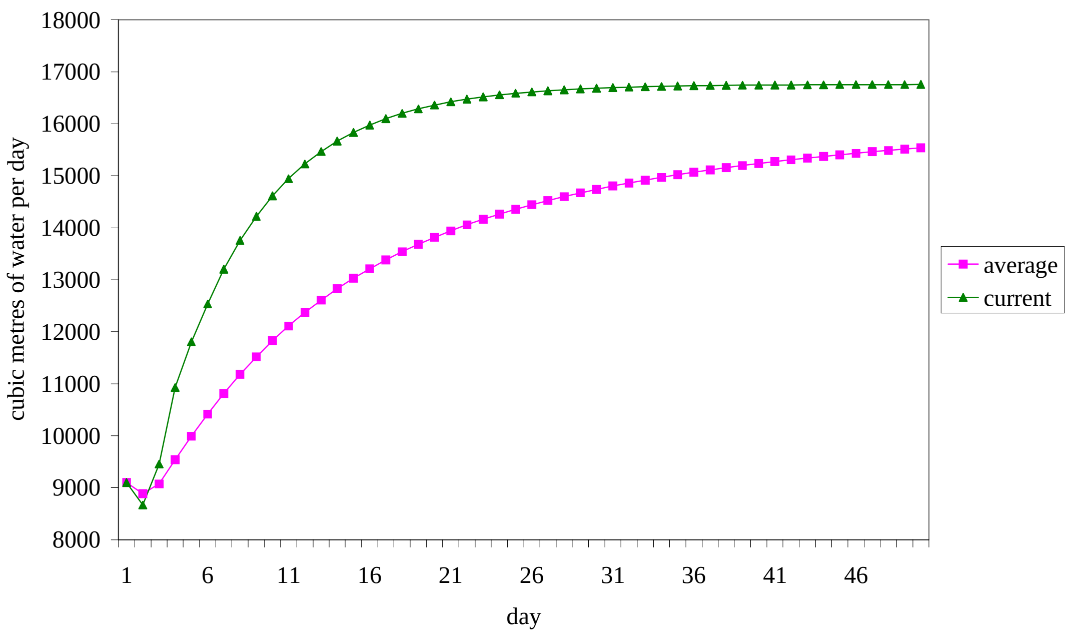

Figure 4.8 Daily water consumption in Amsterdam if it is warm for one day, two consecutive days, three consecutive days, and so on up to 50 consecutive dry days. Displayed are the current consumption at the last day of the warm spell, and the average consumption over the warm spell. Warm is defined as 22°C. Water consumption is relative to the average summer temperature of 17°C.

4.11 Economic costs

The unit price of water varies considerably per region and per supplier. In the province of North Holland, most water is surface water that requires considerable purification. The price is therefore high, around DGl. 3/m^3. Nevertheless, total expenditures on water consumption is low. In Amsterdam, for instance, daily costs are less than DGl. 1/person. Even consumption increases by 10% during an extreme heat wave, costs are limited to a trivial 10 cents per person per day.

4.12 Conclusions

Water consumption is significantly influenced by weather variability, particularly by temperature variations and particularly by long spells of warm weather. This suggests that climate change would increase water demand, but by how much is not sure as this study only included adaptation at the short-term. Managers of water supply companies do not consider the prospects of climate change. Strategic planners do, but focus on the supply side (cf. Van der Grijp and Olsthoorn, 2000). The short term sensitivity found in this analysis warrants further study into this issue.

5. Energy Consumption

Wietze Lise[13], Kees Dorland[13] and Richard S.J. Tol[14]

This chapter examines whether there is a link between energy use and weather variability in Dutch winters by using time series data.

Two main energy components considered here are:

- Gas consumption;
- Electricity consumption.

Data for The Netherlands is available on temperature (daily), sun hours (monthly), energy prices (yearly), gas consumption (monthly for domestic use, industry and power stations), and electricity use (monthly for total use and yearly for a number of sectors). Cf. Chapter 1. Day length is another relevant variable in energy use since electricity consumption increases in winter time due to shorter days.

In this chapter, the relation between the monthly summed degree days and electricity and gas use is analysed. The utility companies use the 'degree day' approach for estimating gas use. The number of degree days per day is defined as the daily average temperature minus 18 ^{o}C if the average 24-hour T<18 ^{o}C. So:

$$DD = 18°C - T (\text{average over 24 hours})$$

A degree-day in the winter requires more energy than a degree-day in summer. A weight factor is therefore applied. The weight factors, which are commonly used in The Netherlands, are presented in Table 5.1.

Table 5.1 Degree-days weight factor.

Months	Multiplication factor
November-February	1.1
March-October	1.0
April-September	0.8

5.1 Methodology: a comparison between regression models used

For estimating the link between gas or electricity and extreme weather events, a number of regression models can be used. First of all, the linkages have been investigated with yearly data using the following model:

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14 Centre for Marine and Climate Research, Hamburg University, Germany; Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands; Center for Integrated Study of the Human Dimensions of Global Change, Carnegie Mellon University, Pittsburgh, PA, USA.

$$X_t = \beta_0 + \beta_1 X_{t-1} + \beta_2 year + \beta_3 W_t + \beta_4 W_{t-1} + \beta_5 p_t^X + \text{error} \tag{5.1}$$

Where is X_t is the energy variable of interest (gas or electricity), t is actual year and W_t is the weather indicator (temperature or degree-days as defined above) and p_t^X is the price of commodity X at time t.

A more detailed analysis is possible by analysing monthly data. The general monthly model has the following shape:

$$\begin{aligned} X_t &= \beta_0 + \beta_2 M_2 + \beta_3 M_3 + \beta_4 M_4 + \beta_5 M_5 + \beta_6 M_6 + \beta_7 M_7 + \beta_8 M_8 \\ &+ \beta_9 M_9 + \beta_{10} M_{10} + \beta_{11} M_{11} + \beta_{12} M_{12} + \beta_{13} t + \beta_{14} X_{t-1} + \beta_{15} X_{t-12} \\ &+ \beta_{16} W_t + \beta_{17} W_{t-1} + \beta_{18} W_{t-12} + \beta_{19} p_t^X + \text{error} \end{aligned} \tag{5.2}$$

The model is extended by including monthly dummies M_i, which are valued one in month i and zero otherwise. These dummies may also be omitted. As before, trend t is a monthly counter.

For electricity use, the temperature variable needs to be corrected for day length in order to see the actual impact of temperature changes on electricity use. Filtering out the day length using an auxiliary regression can do this.

$$W_t = \alpha_0 + \alpha_1 \text{Daylength}_t + \overline{W_t} \Rightarrow \overline{W_t} = W_t - \alpha_0 - \alpha_1 \text{Daylength}_t \tag{5.3}$$

The residual of the auxiliary regression (5.3) is saved as $\overline{W_t}$, which describes the influence of weather, where the influence of day length is filtered out. The same analysis as before can be undertaken after substituting $\overline{W_t}$ for W_t in equation (5.2).

5.2 Annual gas consumption

Equation (5.1) can be applied to fit the link between gas/electricity use and weather variability using yearly data. Temperature degree-days are a good indicator for gas use. Sun hours do not significantly influence gas consumption (results not shown).

The monthly gas data are aggregated into yearly data. After lagging only 19 relevant observations remained. This led to the following significant results.

Gas use for power generation is not related to degree-days, because power plants use gas to generate electricity. There is no link between electricity and weather (cf. Chapter 2).

The outcome of regression with yearly data on gas use and degree-days is promising and shall be analysed more deeply in the following sections. The inclusion of the gas price (if significant) leads to two opposite results. For domestic gas use, a higher gas price reduces the use of gas, while the opposite relation is found for power plants. The link of gas prices with domestic gas use provides the right incentives for users to minimise their gas consumption. The opposite link between gas prices and gas use by power plants is hard to explain.

Table 5.2 Regression results for annual gas consumption in The Netherlands.[a]

	Domestic	Industrial	Power plants	Total
Constant	-258821	-275086	198919	-183335*
	(58118)	(96811)	(76906)	(186560)
Trend	0.638	140.56	-98.08	97.01**
	(0.093)	(49.40)	(38.28)	(95.50)
DV(-1)[b]	132.095	0.51	0.85	0.77
	(29.33)	(0.23)	(0.13	(0.18)
DD[c]	6.146	1.00*	-0.81**	6.15
	(0.37)	(0.56)	(0.78)	(1.02)
DD(-1)	-3.909	-0.08**	-1.58*	-6.68
	(0.66)	(0.56)	(0.75)	(1.42)
Price	-53.706	-29.91**	100.09	42.44**
	(14.11)	(21.73)	(23.64)	(47.34)
Adj. R^2	0.964	0.812	0.732	0.895
N[d]	19	19	19	19

[a] Standard errors are given in brackets.
[b] Dependent variable, lagged by one year.
[c] Degree days.
[d] Number of observations in sample.
* Significancy level between 90 and 95%.
** Not significant.

5.3 Monthly electricity consumption

For modelling the link between total monthly electricity use (EUT) and climate, we need to adjust degree days for day length:

$$DD = \underset{(19.16)}{873.73} - \underset{(1.48)}{48.40}\, DL; \mathrm{Adj\,R}^2 = 0.708, \mathrm{N} = 443$$

As an alternative explanatory variable, we use sun hours, also corrected for day length:

$$SH = -\underset{(6.63)}{104.34} + \underset{(0.51)}{18.26}\, DL, \mathrm{Adj\,R}^2 = 0.747, \mathrm{N} = 441$$

Temperature was used as a third alternative explanatory variable, but no significant relationship with electricity consumption was found.

We can see that the unlagged degree-days are significant only with 90% confidence.
It indicates that a temperature increase can increase the consumption of electricity.

However, adding price and monthly dummies, the regression results change drastically. Current degree days are not significant any longer. Electricity consumption is below average in April and above average in March. The estimated coefficient of the price of electricity is negative, as expected.

The introduction of air conditioning in The Netherlands may have changed the relationship between electricity consumption and weather. Therefore, we split the sample. We find for the period 1978-1997 that a lower temperature leads to a higher use of electricity, and that a higher temperature leads to higher electricity use in the period 1957-1977. This suggests that air-conditioning was more wide-spread in earlier days, and electric heating was more wide-spread in later days. This is opposite to the hypothesised relationship. Note that cooling degree-days may not be the appropriate variable for researching such a relationship.

Table 5.3 Regression results for alternative models for monthly electricity consumption in The Netherlands.[a]

	Base model	Alternative model	1957-1977	1978-1997	Sun hours
Constant	207.69	246.939	113.56	180.82	-153.30
	(18.80)	(20.38)	(24.48)	(74.94)	(17.39)
DV(-1)[b]	0.25	0.27	0.41	0.16	0.23
	(0.03)	(0.03)	(0.05)	(0.03)	(0.03)
DV(-12)	0.73	0.75	0.60	0.82	0.75
	(0.03)	(0.03)	(0.05)	(0.03)	(0.03)
DD[c]	0.18*		-0.32	0.35	
	(0.11)		(0.16)	(0.12)	
DD(-1)	-0.20				
	(0.09)				
DD(-12)	-0.36	-0.39	-0.11**	-0.62	
	(0.10)	(0.07)	(0.15)	(0.12)	
SH[d]					0.30**
					(0.19)
SH(-1)					0.38
					(0.19)
Price		-12.29			
		(1.91)			
March		67.57			
		(24.48)			
April		-41.29*			
		(23.83)			
Adj. R^2	0.992	0.993	0.987	0.953	0.993
N[e]	431	395	191	239	395

[a] Standard errors are given in brackets.
[b] Dependent variable, lagged by one month.
[c] Degree days, corrected for day length.
[d] Sun hours, corrected for day length.
[e] Number of observations in sample.
* Significancy level between 90 and 95%.
** Not significant.

The number of sun hours (corrected for day length) may have an effect on electricity. However, we find the counter-intuitive result that more sun hours increase the demand for electricity.

5.4 Monthly gas consumption

Equation (5.3) is estimated for gas use with and without monthly dummies. Degree days are applied as weather indicator. The results are presented below. In the equations without monthly dummies, the gas price is always included, while it only enters the equation with the monthly dummies if significant.

The findings of the annual analysis are confirmed. Cold weather leads to an increase of domestic, industrial and total gas consumption. Gas consumption for power generation is not affected by weather (because it is transformed to electricity).

Table 5.4 Regression results for alternative models for monthly electricity consumption in The Netherlands.[a]

	Domestic		Industrial		Power plants		Total	
Constant	41.44**	64.20**	123.40*	242.31	-121.29*	-3.02**	-36.72**	98.55**
	(63.82)	(59.61)	(63.83)	(44.80)	(63.20)	(43.11)	(160.97)	(70.40)
DV(-1)[b]	0.15	0.34	0.46	0.69	0.65	0.77	0.36	0.60
	(0.0)	(0.06)	(0.06)	(0.05)	(0.05)	(0.04)	(0.06)	(0.05)
DV(-12)	0.56	0.31	0.32		0.23	0.11	0.40	0.16
	(0.0)	(0.06)	(0.05)		(0.05)	(0.04)	(0.06)	(0.05)
Trend	0.52	0.50	0.30	0.26	0.14**		1.01	0.78
	(0.11)	(0.11)	(0.07)	(0.05)	(0.09)		(0.21)	(0.18)
DD[c]	5.74	5.78	0.39	0.34	0.04**		6.19	6.29
	(0.09)	(0.09)	(0.05)	(0.03)	(0.08)		(0.16)	(0.14)
DD(-1)	-0.56*	-1.80	-0.25	-0.24	-0.17		-2.18	-3.40
	(0.33)	(0.37)	(0.04)	(0.04)	(0.05)		(0.38)	(0.35)
DD(-12)	-3.25	-1.82	-0.11		0.10**		-2.32	-1.08
	(0.30)	(0.35)	(0.05)		(0.08)		(0.39)	(0.33)
Price	-4.21	-4.01	-1.13*	-1.89	3.27	1.95	0.53**	
	(1.00)	(1.91)	(0.60)	(0.47)	(0.82)	(0.73)	(1.89)	
Feb		-177.61		-69.90		-63.28		-349.96
		(32.68)		(12.34)		(18.74)		(44.61)
Mar		-58.66		54.13		52.04		
		(28.55)		(12.82)		(18.54)		
Apr		-80.45		-43.90		-77.73		-190.31
		(29.36)		(11.85)		(18.82)		(41.51)
May		-149.31				-73.48		-194.44
		(27.62)				(18.95)		(38.58)
Jun		-59.69						-74.54
		(23.03)						(36.54)
Jul								
Sep						53.62		
						(18.71)		
Oct		-87.30		94.56		68.88		
		(25.88)		(10.85)		(18.69)		
Nov		-108.12						-115.56
		(28.21)						(37.57)
Dec		-49.66*						
		(27.17)						
Adj. R^2	0.993	0.995	0.844	0.889	0.704	0.762	0.984	0.988
N[d]	227	227	227	238	227	227	227	239

[a] Standard errors are given in brackets.
[b] Dependent variable, lagged by one month.
[c] Degree days.
[d] Number of observations in sample.
* Significancy level between 90 and 95%.
** Not significant.

Average domestic gas use is equal to 22,726 million m^3 per year. An increase of 1^oC is approximately equal to an increase of 350 degree-days, leading to (5.735-3.25)*350/22726=3.8% decrease in domestic gas use.

Average industrial gas use is equal to 11,764 million m^3 per year. An increase of 1^oC is approximately equal to an increase of 350 degree-days, leading to (0.392-0.105)*350/11764 =0.9% decrease in industrial gas use.

Average total gas use is equal to 42,400 million m^3 per year. An increase of 1^oC is approximately equal to an increase of 350 degree-days, leading to (6.185-2.323)*350/42400 =3.2% decrease in total gas use.

5.5 Iterative estimation of weather impact on gas use

It is possible to account for higher order effects from weather. This can be calculated iteratively by applying the model of Elkhafif (1996). The iteration model of Elkhafif works as follows. The basic model that has to be estimated has the following form, taking i=0:

$$X_t^i = \beta_0^i + \beta_1^i X_{t-1}^i + \beta_2^i X_{t-12}^i + \beta_3^i t + \mathrm{C}i \times DD_t + \beta_5^i p_t^X + \text{error} \tag{5.4}$$

Here DD represents degree-days, which enters the equation *without lags*. After this regression, the indicator of interest X_t^i is updated in the following manner:

$$X_t^i = X_t^0 - \sum_{j=0}^{i-1} \mathrm{C}j \left(DD_t - \overline{DD} \right) \tag{5.5}$$

Where $\overline{DD}$ stands for the average value of the DD over the total data set. In the next step equation (5.4) is regressed again for i=1. After that X_t^i is calculated, using equation (5.5) and equation (5.4) is regressed again for i=2. This iteration is repeated until C_i becomes insignificant. Then we have $\sum_{j=0}^{i-1} \mathrm{C}j$ as the desired coefficient for the *absolute* impact of weather.

Elkhafif (1996) shows that domestic use of gas is more susceptible to weather conditions than industrial use. This is rather obvious since the domestic purpose is to heat the house, whereas the industrial purpose is to complete the production process, which links to weather less obviously. He suggests to correct energy data for weather to avoid misleading results. Correction of the data can be done through an iterative regression procedure where the coefficient of the weather variable is estimated until it becomes insignificant. In each step the energy variable is corrected for the estimated impact of the climate variable. This is especially useful for gas use. He suggests that for electricity data cooling days (number of days above 18) should be included as well in the regression equation.

The Elkhafif corrections are also estimated for our monthly gas data. This leads us to the following correction coefficients:

Table 5.5 Elkhafif corrections.

	Domestic gas use	Industrial gas use	Gas use by power plants	Total gas use
C1	5.487	0.137	Not significant	5.858
C2	0.430			-5.262
C3	0.179			-0.110
C4				-0.067
C5				-0.046
Total	6.096	0.137		0.373

For instance the link between degree-days on domestic gas use is not 5.487, but 6.096.

5.6 Conclusions

The link between gas/electricity use and (extreme) weather events is studied using time series data for The Netherlands. Analyses with yearly data provide no link at all for electricity, while gas use reduces when the average temperature increases. Domestic users of gas are sensitive to gas price changes. Analyses with monthly data provide a weak but expected link between electricity use and degree days, which are corrected for the day length. The most interesting outcome is derived for monthly gas use data, where an increase of 1^{o}C in the average temperature shall lead to a decrease of 3.8% for domestic gas, 0.85% for industrial gas use and 3.2 % for total gas use. This is equal to a reduction of DGl. 389 million for domestic gas use, DGl. 45 million for industrial gas use and DGl. 611 million for total gas use.

6. Modelling Storm Damage in The Netherlands and the UK

Kees Dorland[15], Jean Palutikof[16] and Richard S.J. Tol[17]

Extreme weather events are an integral part of weather variability. This chapter presents a summary of the results of the modelling effort of storm damage in The Netherlands and the United Kingdom. This work is an extension to earlier work on storm damage modelling by the authors (Dorland *et al.,* 1999).

6.1 The Netherlands

6.1.1 Introduction

The storm damage model for The Netherlands is based on the storms listed in Table 6.1. Both insurance loss and meteorological data were collected.

Table 6.1 Storm events included in the storm damage analysis for The Netherlands and the storm specific average maximum hourly average wind speed ($\bar{V}_{max}$) and maximum hourly windgust ($\hat{V}_{max}$) in m/s.

No.	Year	Month and day	$\bar{V}_{max}$ (m/s)	Std. $\bar{V}_{max}$ (m/s)	$\hat{V}_{max}$ (m/s)	Std. $\hat{V}_{max}$ (m/s)
1	1987	October 15-17	16.8	2.2	28.2	2.4
2	1989	February 19	12.2	1.6	19.1	1.7
3	1989	December 21	14.2	1.3	22.5	1.1
4	1990	January 25-26	22.7	1.6	36.7	1.9
5	1990	February 25 – March 1	20.5	1.9	34.4	1.6
6	1990	December 26	16.2	1.8	25.3	1.8
7	1991	January 6-8	16.9	1.7	26.0	1.7
8	1991	December 22-24	15.8	1.5	26.0	1.1
9	1992	November 11	17.1	1.6	26.1	1.6
10	1992	November 25-27	17.4	1.0	28.6	1.3
Average			17.0	3.2	27.3	5.2

6.1.2 Insurance loss data

The insurance data on a 2-digit postal level data were obtained from the Centre for Insurance Statistics (CVS), The Hague, The Netherlands. The data contained the average

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insured sum, the claim density and the average storm damage for residential buildings (non excl. apartments) with a value smaller than 500,000 DGl. (226,886 €) and businesses with a value smaller than 10 million DGl. (4,537,720 €) in the portfolio of the insurance companies that supply data to the CVS. These portfolios include about 80% of the total insurance market in The Netherlands. The insurance loss data used in this study includes the claims and losses in a period of three days before until three days after the storm.

The total insured damages due to a storm event is estimated by linearly extrapolating the claim density and the average claim loss in the data supplied by CVS to the whole residential buildings and businesses stock in The Netherlands. It was assumed that the CVS data gives a good representation of the average stock and insurance in the postal areas.

6.1.3 Meteorological data

The following meteorological data for these storms and for the 29-33 meteorological measurement stations in The Netherlands were obtained from the Meteorological Office in The Netherlands (KNMI):

- maximum hourly average wind speed ($\bar{V}_{max}$) in m/s;
- maximum hourly windgust ($\hat{V}_{max}$) in m/s;
- storm duration (Dur) in hours (defined as the number of hours that the maximum hourly windgust exceeds 27 m/s); and
- prevailing wind direction (Dir) in degree (North is 360^{o} and South is 180^{o}) .

Storm intensity ($\hat{V}_{max}$ and $\bar{V}_{max}$), storm duration and storm direction maps were derived by distance-related weighted spatial interpolation between the measurement sites. The radius was set at 100 km and weight of the contribution of the stations was set to decrease linearly with the distance from the measurement station. The wind data so derived were again aggregated to the level of the storm damage data, i.e. the two-digit postal code level, by (arithmetically) averaging over the grids in postal code areas. This results in values for $\hat{V}_{max}$, $\bar{V}_{max}$, storm direction and duration for every postal code area *i* and every storm event *t*. This interpolation and the aggregation were carried out with the geographical information system ArcView. This procedure makes no allowance for differences in topography and surface roughness. According to Cook (1985) these factors are important determinants of spatial variations in the near-surface hourly mean wind speed. However, these data were not available to the project. According to Deacon (1955) these factors are less important for the spatial variation of the near-surface windgust. The arithmetic mean of the interpolated V

^

$_{max}$ and
V

–

$_{max}$ values for the individual storms and the average
$\hat{V}_{max}$ and $\bar{V}_{max}$ values over all storms are presented in Table 6.1.

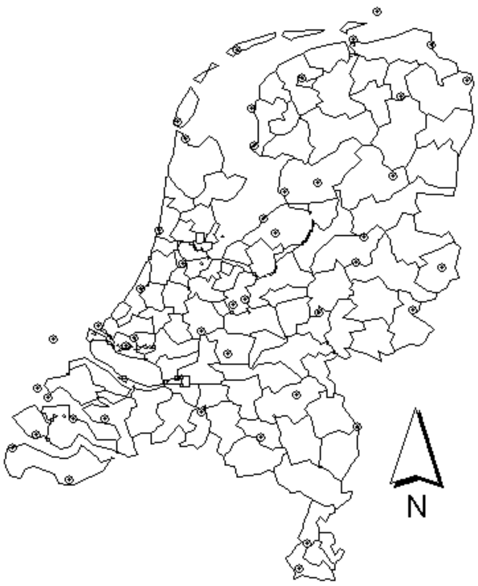


Figure 6.1 Meteorological stations and 2-digit postal level for the Netherlands.

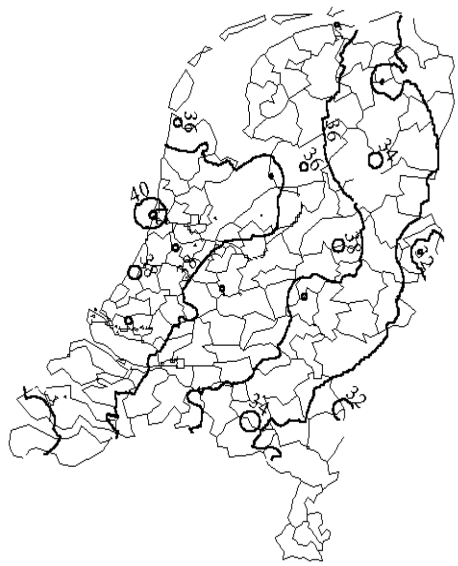


Figure 6.2 Interpolated windgust field (m/s) for the January 1990 storm.

6.1.4 Modelling

First, the area specific data were tested for correlation. There is a statistically significant correlation between the wind speed parameter and storm duration parameter. Therefore, a corrected storm duration (the residuals of the storm duration versus the wind speed indicator instead of the storm duration itself) is used for the modelling analysis. The residuals of the regression of the linear and the logarithmic relation between the storm duration and the wind speed parameter were included in the square, cubic and exponential models respectively. All these type of relations have been described in the literature (amongst others by Cook, 1985; Christofides *et al.*, 1992 and Schraft *et al.*, 1993).

Next, it was analysed which variables to include. The variables number of residential buildings and businesses, surface area, density of the residential buildings and businesses, average income households, wind direction, corrected storm duration and wind speed ($\hat{V}_{max}$ and $\bar{V}_{max}$) were tested for their explanatory power. For these tests square, cubic and exponential relations of the wind speed parameter to the loss indicators (claim density CD and insured damage ID) were analysed. The variables were not included if their t-statistics is smaller than1 or if the change in Log Likelihood (LL) when leaving the variable out of the regression is not larger than 1. The regression results indicate that wind direction should not be included in any of the functional forms for insured damages to businesses. The surface area and the density of the stock at risk should not be included in the square and cubic functional forms for insured damages to residential buildings and businesses nor in the exponential relation for businesses.

Next the linear and exponential functional form have to be compared to see which model gives a better relation. This was done by comparing the metric-adjusted Log Likelihood of regression (see Box and Cox, 1962). The exponential functional form was found to give a lower variance than the square and cubic functional forms and thus is statistically preferred. Furthermore the $\hat{V}_{max}$ parameter was preferred over the $\bar{V}_{max}$ parameter for both residential buildings and businesses.

The model was fitted to nine storms on which the loss indicator for the tenth storm was projected (a forecast test). For the October 1987, the February 1989, the January 1990 and the December 1991 storms the probability that the model for the individual storm is not different from the model for all other storms is larger than 0.05. This means that the models for the individual storms are different from the model for all other storms. This indicates that the data set is not best described by one function.

It was analysed if a geographical differentiation of the model was needed. For this purpose two tests were performed. In the first group of tests, The Netherlands was divided in North versus South and West versus East. In the second group of tests, the areas with different building standards were compared. The results (not shown) indicate that the functions for the regions are not different ($p< 0.05$). This means that the vulnerability of the objects in the different areas are not statistically significant different. This could indicate that the building standards result in an equalisation of the vulnerability.

The parameters were tested for stability over the ordered observations. The wind speed parameter was found to have two breakpoints at 23.7 m/s and at 32.9 m/s for residential building, while only one breakpoint was identified at 24.8 m/s for businesses.

The parameters were again tested for their explanatory value for the different data sub-sets. For wind speeds below 23.7 m/s and 24.8 m/s (mainly storms 2 and 3), no relation between the wind speed parameter and the insured damages is found for residential buildings and businesses respectively. This indicates that at low wind speeds (below 23.7 and 24.8 m/s for residential buildings and businesses, respectively) the damages are more random than at higher wind speeds. For private houses, the wind direction was shown to be not statistically significant between wind speeds of 23.7 m/s and 32.9 m/s. For wind speeds in excess of 32.9 m/s, the corrected storm duration parameter was not statistically significant. In this last regression (mainly storms 4 and 5) the wind direction parameter is positive and statistically significant. This means that the storm duration is not important for the damages at high windgusts while it is for lower windgusts and that the damages at higher windgusts increase with the wind direction becoming more north westerly.

The model can thus be represented by:

$$\ln (LI_{i,t}) = \alpha \ln (O)_{i,t} + \beta \ln (A)_{i,t} + \chi \ln (dir)_{i,t} + \delta\, durres + \varepsilon (\hat{V}_{max})_{i,t} + C \qquad (6.1)$$

with:

$$durres = \ln (dur)_{i,t} - \phi (\hat{V}_{max})_{i,t} - C \qquad (6.2)$$

where:

$LI_{i,t}$	=	loss indicator, that is, insured damage (in €) for residential buildings or businesses in area *i* for storm event *t*;
$O_{i,t}$	=	number of objects (residential buildings or businesses) in area *i* for storm event *t*;
$A_{i,t}$	=	postal code area *i* for storm event *t* (in km^2);
$\hat{V}_{max;i,t}$	=	storm input data in area *i* for storm event *t*;
$dir_{i,t}$	=	wind direction in area *i* for storm event *t*;
$dur_{i,t}$	=	storm duration in area *i* for storm event *t* ;
$durres_{i,t}$	=	residuals of the regression of storm duration in area *i* for storm event *t* ($dur_{I,t}$) to $\hat{V}_{max;i,t}$;
c	=	constant;
$\alpha,\beta,\chi, \delta, \varepsilon, \phi$	=	coefficients;
i	=	postal code area number (10,11,..,99); and
t	=	storm event number (1,2, …,10).

The parameter estimates of the exponential regression of the windgust to the storm duration for the business data set with windgusts over 28.4 m/s are presented in Table 6.2. For the residential building data set with wind speeds over 32.9 m/s there appeared no correlation between the storm duration and the windgust.

Table 6.2 Estimated parameters of the logarithmic storm duration to the windgust; see equation (6.2).

Variable	Coefficient	Std. Error	t-Statistic	R^2	F-statistic	Log likelihood
Business buildings (N= 617, wind in excess of 24.8 m/s)						
C – constant	-0.988	0.20	-4.87	0.31	276.3	-647.8
ϕ – wind speed	0.117	0.007	16.6			

The resulting parameter estimates of the uncorrected (residuals of the duration to wind-gust regression) damage model for businesses is presented in Table 6.3.

Table 6.3 Estimated parameter values of the exponential relation for the insured damages to businesses; see equation (6.1).

Parameter	Coefficient	Std. Err.	t-Stat.
Businesses (buildings)	**N=439 (windgust > 24.8 m/s)**		
C – constant	-10.1	1.3	-8.0
α – # objects	0.58	0.10	6.0
β – area	0.39	0.09	4.2
χ – direction			
δ – duration	-0.29	0.08	-3.7
ε – wind speed	0.44	0.01	32.5
R^2	0.70		
LL	-808.6		
SSR	767.6		
F-stat.	289.9		
DW stat.	1.70		

Substituting equation (6.2) in equation (6.1), with the parameter estimates found in Tables 6.2 and 6.3, respectively, gives the results in Table 6.4.

Substituting (6.2) in (6.1) gives:

$$\ln (LI_{i,t}) = \alpha \ln (O)_{i,t} + \beta \ln (A)_{i,t} + \chi \ln (dir)_{i,t} + \delta \ln (dur_{i,t}) + \varepsilon (\hat{V}_{max})_{i,t} + C \qquad (6.3)$$

where:

$LI_{i,t}$	=	loss indicator, that is, insured damage ID (in €) or claim density CD (in ‰) for residential buildings or businesses in area *i* for storm event *t*;
$O_{i,t}$	=	number of objects (residential buildings or businesses) in area *i* for storm event *t*;
$A_{i,t}$	=	postal code area *i* for storm event *t* (in km^2);
$\hat{V}_{max;i,t}$	=	storm input data in area *i* for storm event *t*;
$dir_{i,t}$	=	wind direction in area *i* for storm event *t*;
$dur_{i,t}$	=	storm duration in area *i* for storm event *t* ;
C	=	constant;
$\alpha,\beta,\chi, \delta, \varepsilon$	=	coefficients;
i	=	postal code area number (10,11,..,99); and
t	=	storm event number (1,2, …,10).

Equation (6.3) was directly estimated for private houses. The parameter estimates are given in Table 6.5.

Table 6.4 Estimated parameter values of the exponential relation for the insured damages models for businesses.

	N=439 $\hat{V}_{max}$ > 24.8 m/s	
Parameter	Coefficient	Standard Error
C – constant	-10.4	1.3
α – # objects	0.585	0.097
β – area	0.390	0.092
χ – direction		
δ – duration	-0.291	0.078
ε – wind speed	0.474	0.014

The wind direction shows a negative relation to the loss indicators. This means that the loss indicators increase with a more south-westerly wind direction (the wind direction during the storm events mainly varied from north-northwest to south-southwest).

Table 6.5 Estimated parameter values of the exponential relation for the insured damages models for private residential buildings.

Residential buildings	N=516 23.7< $\hat{V}_{max}$ < 32.9 m/s			N=162 $\hat{V}_{max}$ > 32.9 m/s		
Parameter	Coeff.	Std. Err.	t-stat	Coeff.	Std. Err.	t-stat
C – constant	-22.4	2.9	-7.8	-1.2	1.8	-0.69
α – # objects	0.93	0.09	10.5	0.66	0.10	6.9
β – area						
χ – direction	1.85	0.47	3.9			
δ – duration				-0.47	-0.09	-5.5
ε – wind speed	0.447	0.024	18.7	0.270	0.03	7.9
R^2	0.48			0.56		
LL	-804.9			-178.9		
SSR	684.0			86.4		
F-stat.	155.3			67.8		
DW stat.	1.80			2.1		

The modelled and observed damages for each storm are compared in Table 6.6. The ratio of the modelled to the observed damages for the 1989 storms (storms 2 and 3) are very low. This is due to the fact that, in these storms, windgusts were typically below the windgusts that are included in the model, although damages were observed. This means that no damages are modelled. For the other storms the modelled and observed insured damages to residential buildings are not statistically different except for the 1992 storms. The modelled to observed damage ratios are between 0.44 and 1.79, i.e., damages are no more than 56% underestimated and no more than 79% overestimated. For businesses, the modelled damages differ significantly from the observed damages for only 4 of the 8 storms. However, the modelled to observed damage ratio are between 0.65 and 1.40. So, this indicates that the models for both residential buildings and business buildings and contents seem to describe the storm impacts reasonably well.

*Table 6.6 Observed and modelled damages (in million € at 1990 values) for the individual storm events in The Netherlands. Two times the standard deviation (2*sd) in the modelled damages and the ratio of the modelled to the observed damages are also presented.*

			Residential buildings				Businesses			
No.	Year	Month and day	Obs.	Mod.	2*sd	Ratio (Mod./Obs.)	Obs.	Mod.	2*sd	Ratio (Mod./Obs.)
1	1987	October 15-17	3.9	7.1	5.5	1.79	1.8	2.5	1.0	1.39
2	1989	February 19	1.5	0.0	0.0	0.00	0.37	0.00	0.00	0.00
3	1989	December 21	0.73	0.10	0.07	0.14	0.37	0.00	0.00	0.00
4	1990	January 25-26	401	330	88	0.82	137	101	30	0.74
5	1990	February 25 – March 1	95	77	19	0.82	18	20	6	1.06
6	1990	December 26	1.3	1.0	0.4	0.83	0.67	0.43	0.15	0.64
7	1991	January 6-8	1.5	1.6	0.5	1.06	0.69	0.46	0.15	0.67
8	1991	December 22-24	1.3	2.0	0.6	1.52	0.63	0.61	0.17	0.96
9	1992	November 11	5.1	2.3	0.7	0.44	2.5	0.8	0.2	0.33
10	1992	November 25-27	8.9	5.0	1.4	0.56	3.6	3.0	0.9	0.85

6.1.5 Prospects under climate change

What can be expected for future storm damages under climate change?

In Dorland *et al.* (1999), we argue that an increase of the intensity of storms (the win-gust) of 2% in 25 years and 6% in 75 years is conceivable. These increases are based on detailed analyses by amongst others Palutikof and Downing (1994), Murphy (1994) and UKCCIRG (1996). In the latter studies the increase in the mean wind speed are analysed whereas Palutikof and Downing (1994) assume a pro rata increase of the windgust. Katz and Brown (1992) argue that this is a conservative estimate as the increase in the windgust is likely to be even higher than the increase in the mean wind speed.

There is an exponential relationship between storm damage and windgust. Storm damage would increase dramatically if windgust increase slightly. The results for two storms – January 25-26 1990 and November 11 1992 – are presented in Table 6.7. The results for the November 11, 1992, storms are presented in Figure 6.3. Insured damages to residential buildings and businesses would increase by 30 to 80% and 40 to 200%, respectively, would wind speed increase by 2 to 6%.

The increase in the future number and value of the stock-at risk could also lead to an increase of the insured damages. Dorland *et al.* (1999) show that the increase in damage does not strongly depend on demographic and economic growth. When assuming a 0.3% annual demographic growth rate and a 2.8% annual economic growth rate increase in the number of the stock-at-risk would lead to an increase of the insured damages with 8% and 100% for residential buildings and businesses respectively in 25 years. When assuming the insured value of property to increase linearly with economic growth this would again lead to an increase of the insured damages with 100% for both residential buildings and businesses. The changes in wind intensity, housing density and business density lie well within the range of present observations so that extrapolation uncertainties are limited.

Table 6.7 Increase in insured damages of the January 25-26 1990 and November 11 1992 storm events due to a 2-10% increase of the windgust. Two times the standard deviation in the estimates are presented below the estimates.

	January 25-26 1990		November 11 1992	
	Residential buildings	Businesses	Residential buildings	Businesses
Increase in windgust	% increase insured damage		% increase insured damage	
2%	23	44	28	37
2*sd	14	39	30	33
4%	52	106	64	78
2*sd	23	69	48	54
6%	88	196	109	131
2*sd	32	107	69	77
8%	131	325	168	200
2*sd	42	160	94	106
10%	184	510	327	290
2*sd	55	235	192	143
	Increase insured damage (million €)		Increase insured damage (million €)	
2%	77	44	0.6	0.3
2*sd	48	40	0.7	0.3
4%	173	107	1.4	0.6
2*sd	76	70	1.1	0.4
6%	289	198	2.5	1.1
2*sd	106	108	1.6	0.6
8%	431	329	3.8	1.6
2*sd	140	162	2.1	0.9
10%	607	516	7.4	2.4
2*sd	180	238	4.3	1.2
	Total insured damage (million €)		Total insured damage (million €)	
0%	330	101	2.3	0.8
2*sd	65	38	0.8	0.3
2%	407	145	2.9	1.1
2*sd	81	55	1.1	0.4
4%	502	208	3.7	1.5
2*sd	111	89	1.5	0.6
6%	618	299	4.7	1.9
2*sd	153	140	2.2	0.9
8%	761	430	6.0	2.5
2*sd	207	214	3.0	1.2
10%	936	617	9.6	3.2
2*sd	275	320	5.3	1.7

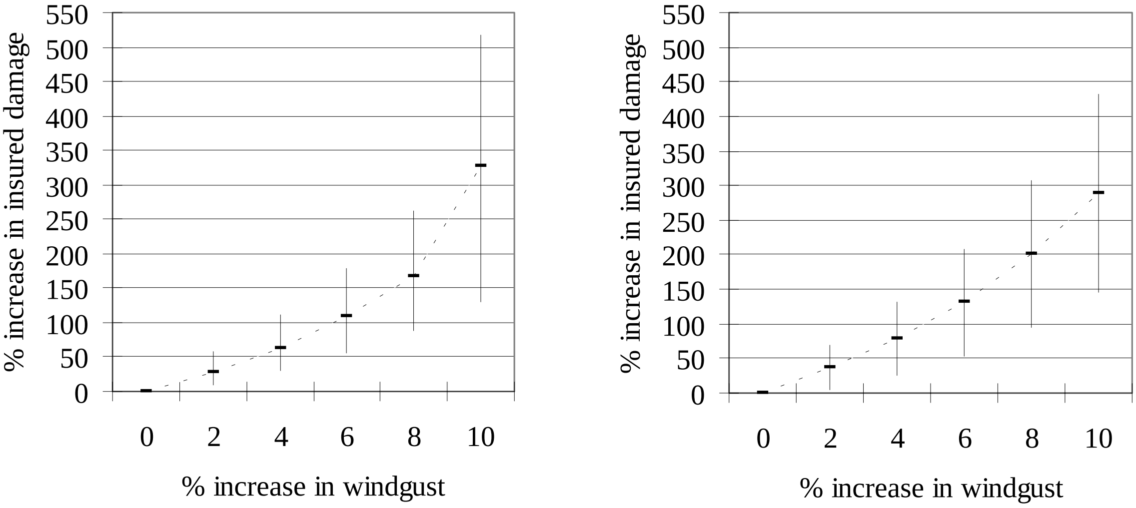


Figure 6.3 Increase in the insured damages to residential buildings (left panel) and businesses (right panel) of the November 11 1992 storm due to a 2-10% increase in the windgust.

6.2 The UK analysis

6.2.1 Introduction

The storm damage model for the UK is based on the storms of 15-17 October 1987, 25 January 1990 and 25-26 February 1990. Both insurance loss and meteorological data were collected. Data are given in Table 6.8.

Table 6.8 Storm events included in the storm damage analysis for the UK and the storm specific average maximum hourly average wind speed ($\bar{V}_{max}$) and maximum hourly windgust ($\hat{V}_{max}$) in m/s.

No.	Year	Month and day	$\bar{V}_{max}$ (m/s)	Standard deviation	$\hat{V}_{max}$ (m/s)	Standard deviation
1	1987	October 15-17	15.9	3.9	27.8	7.4
2	1990	January 25	19.9	3.3	34.8	6.1
3	1990	February 25-26	18.8	1.9	33.6	2.9
Average			18.2	3.6	32.0	6.6

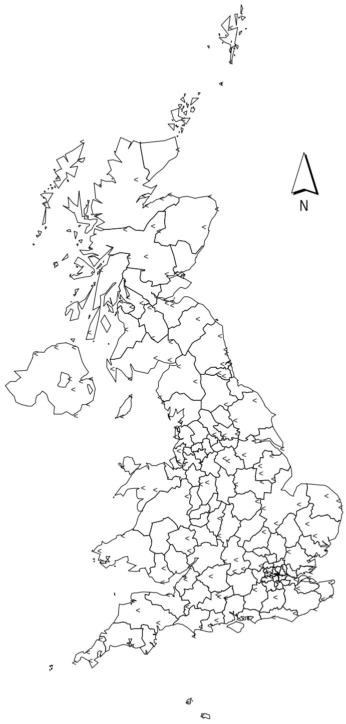
6.2.2 Insurance loss data

The insurance data on a 2-digit postal level data were obtained from the re-insurance company General Accident, Perth, UK. The data contained the total insured sum, the number of policies, the storm damage and the number of claims for residential buildings (all 3 storm events) and rented businesses and the related businesses contents (the January 1990 storm only) in the General Accident (GA) port folio. The data gives the total registered claims and losses in the full month in which the storm occurred. It was assumed that the main claims and losses were related to the storms analysed. However, for the February 1990 storm this assumption is probably rather poor as in this month several severe storm events occurred.

Three loss indicators were generated for the modelling analysis. First the relative damage per insured sum in ‰, the claims per policy in ‰ and the insured damage. The insured damage is estimated by linearly extrapolating the claim density and the average claim loss in the GA portfolio to the whole residential buildings and businesses stock in the UK. It was assumed that the GA portfolio gives a good representation of the average stock and insurance in the postal areas.

6.2.3 Meteorological data

Meteorological data (maximum hourly average wind speed $\bar{V}_{max}$ and maximum windgust $\hat{V}_{max}$ both in m/s, and prevailing wind direction (dir) in degree (North is 360^{o} and South is 180^{o})) for these storms and for 164 meteorological measurement stations in the UK were obtained from the Meteorological Office in the UK. Storm intensity ($\hat{V}_{max}$ and $\bar{V}_{max}$) and storm direction maps were derived by the same method as used for The Netherlands. See Section 6.1.3. The arithmetic mean of the interpolated $\hat{V}_{max}$ and $\bar{V}_{max}$ values for the individual storms and the average $\hat{V}_{max}$ and $\bar{V}_{max}$ values over all storms are presented in Table 6.8.



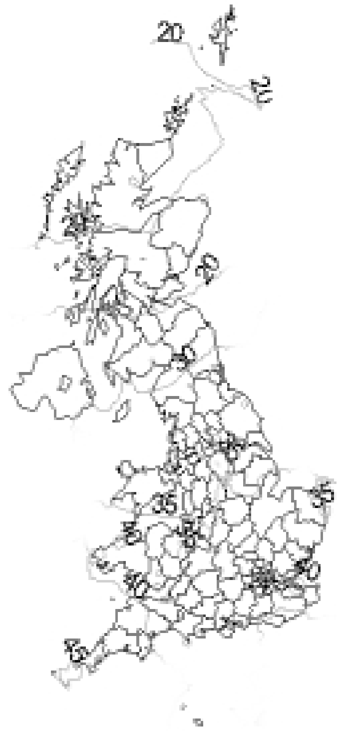


Figure 6.4 Meteorological stations and. 2-digit postal level for the UK (m/s).

Figure 6.5 Interpolated windgust field for the January 1990 storm.

6.2.4 Modelling

The area specific data were tested for correlation. No statistically significant correlations between the variables (number of residential buildings, density of residential buildings, surface area, wind direction and wind speed ($\hat{V}_{max}$ and $\bar{V}_{max}$)) were found.

The variables were tested for their explanatory power. For these tests square, cubic and exponential relations of the wind speed parameter to the loss indicators (relative damage RD, claim density CD and insured damage ID) were analysed. The test results indicate that stock density, surface area and wind direction should not be included in the function in any of the functional forms for damage to businesses and businesses contents. For residential buildings the test results indicate that stock density is not statistically significant (5%) for the ID and RD models and only has a low statistical significance (10%) for the CD model. The same applies to the surface area variable. Thus it is concluded that these variables should not be included in the models.

The linear and exponential functional forms were compared using the metric-adjusted Log Likelihood (Box and Cox, 1962). The exponential functional form was found to give a better fit. Furthermore,
V

$\hat{V}_{max}$ performed better than $\bar{V}_{max}$ for both residential buildings and businesses. For businesses content the functions with the two wind speed parameters were not statistically significant. For coherence $\hat{V}_{max}$ was used in all functions. The model is thus:

$$\ln (LI_{i,t}) = \alpha \ln (O)_{i,t} + \beta \ln (A)_{i,t} + \chi \ln (dir)_{i,t} + \delta (\hat{V}_{max})_{i,t} + C \qquad (6.4)$$

where:

$LI_{i,t}$	=	loss indicator, that is, insured damage ID (in €), relative damages RD (in ‰) or claim density CD (in ‰) for residential buildings, businesses or businesses contents in area *i* for storm event *t*;
$O_{i,t}$	=	number of objects (residential buildings or businesses) in area *i* for storm event *t*;
$A_{i,t}$	=	postal code area *i* for storm event *t* (in km^2);
$(dir)_{i,t}$	=	wind direction in area *i* for storm event *t*;
$\hat{V}_{max;i,t}$	=	storm input data in area *i* for storm event *t*;
c	=	constant;
α,β,χ,δ	=	coefficients;
i	=	postal code area number (1,2, … 125); and
t	=	storm event number (1,2,3).

The model was fitted to two storms from which losses of the third storm was projected (a forecast test). This test could only be performed for residential buildings as for businesses only data for one storm was available. The results indicate that the function that fits the February 1990 data is statistically different from the function that fits the October 1987 and January 1990 data. This could well be due to the fact that the claim and loss data were obtained on a monthly basis while several other severe storm events occurred in February 1990. Therefore, the February 1990 data were excluded from the analysis.

It was analysed whether a geographical differentiation of the model was needed. A division over North versus South and West versus East was performed. The results indicate that the functions for the different regions are not statistically different. This means that based on the available data the vulnerability of the objects in the different areas were not found to be statistically different.

The parameters were then tested for stability over the ordered observations. The parameters were shown to be stable, meaning that one function for each loss indicator can be applied to the whole data set. The final regression results are presented in Table 6.9.

The results for business contents show poor regressions, especially for the relative damages. This could be due to other variables being more important for explaining the losses, such as rainfall, for which no data were readily available for this analysis.

For residential buildings and business buildings, the function for the insured damages showed a non-significant explanatory power for the area and the object density parameter.

For the relative damages function, only the wind direction and the wind speed parameters were found to be statistically significant for residential and business buildings. The number of objects was only just significant in both the residential buildings and businesses functions. However, the objects parameter was not included in the functions as their contribution to the explanatory power was low (change in Log Likelihood <1.2) and the coefficients were contradictory in sign (positive for residential buildings and negative for businesses).

For the relative number of affected policies, the wind speed parameter is statistically significant for both residential buildings and businesses (buildings) whereas the wind direction parameter is only significant in the function for residential buildings.

The wind direction shows a negative relation to the loss indicators for residential buildings. This means that the loss indicators increase with a more south-westerly wind direction (the wind direction during the storm events mainly varied from north-northwest to south-southwest).

The modelled and observed damages are compared for each of the storms in Tables 6.10 and 6.11. The modelled and observed insured damages to residential buildings are not statistically different for the 1990 storm whereas they are for the 1987 storm. For the damages to business buildings and contents, the modelled and observed damages are not statistically different for all loss indicators. The modelled to observed damage ratios for residential buildings are between 0.57 and 1.14 (that is, damages are up to 43% underestimated and up to 14% overestimated). For business buildings and contents, the ratios are between 0.73 and 0.97. This indicates that the model for residential buildings, business buildings and business contents seems to describe the storm impacts well.

Table 6.9 Estimated parameter values of the exponential relation for the loss indicators (insured damage ID, relative damages RD and claim density CD) for private residential buildings, businesses and businesses contents in the UK.

	ID			RD			CD		
Parameter	Coeff.	S.E.	t-Stat.	Coeff.	S.E.	t-Stat.	Coeff.	S.E.	t-Stat.
Residential Buildings	**N=228**			**N=230**			**N=226**		
C – constant	0.4	2.7	0.15	-1.1	2.4	-0.43	4.1	1.7	2.4
α - # objects	1.06	0.09	11.2						
β - area									
χ - direction	-1.50	0.44	-3.4	-1.76	0.44	-4.0	-1.61	0.31	-5.2
δ - wind speed	0.312	0.007	42.7	0.283	0.007	38.2	0.256	0.005	49.1
R^2	0.91			0.87			0.92		
LL	-271.5			-280.7			-190.0		
SSR	144.5			154.7			71.1		
F-stat.	726.9			765.8			1291.1		
DW stat.	1.96			1.91			1.89		
Businesses (buildings)	**N=113**			**N=114**			**N=113**		
C – constant	-1.57	0.71	-2.2	-6.96	0.46	-15.0	-1.10	0.32	-3.5
α - # objects	0.92	0.09	9.7						
β - area									
χ - direction									
δ - wind speed	0.219	0.013	17.1	0.205	0.013	15.8	0.164	0.009	18.6
R^2	0.85			0.69			0.76		
LL	-114.1			-127.7			-84.1		
SSR	49.8			62.7			29.2		
F-stat.	305.1			250.8			346.5		
DW	1.6			1.81			1.91		
Businesses (contents)	**N=82**			**N=83**			**N=82**		
C	2.1	1.2	1.7	-6.1	1.5	-4.0	1. 6	1.1	1.5
α	0.46	0.14	3.2				-0.60	0.10	-5.8
β							0.185	0.054	3.4
χ									
δ	0.149	0.020	7.4	0.121	0.041	3.0	0.116	0.015	7.6
R^2	0.50			0.099			0.51		
LL	-88.7			-151.7			-61.4		
SSR	41.8			194.0			21.5		
F-stat.	38.8			8.8			26.9		
DW	1.28			1.76			1.60		

*Table 6.10 Observed and modelled damages to residential buildings (in billion € at 1990 values) for the October 1987 and the January 1990 storm events in the UK. Two times the standard deviation (2*sd) in the modelled damages and the ratio of the modelled to the observed damages are also presented.*

	Observed	Modelled	2*sd	Ratio modelled/observed
Insured damages				
1987	1.63	1.12	0.47	0.69
1990	2.28	2.30	0.54	1.01
Relative damages				
1987	1.63	0.92	0.36	0.57
1990	2.28	2.60	0.68	1.14
Claim density				
1987	1.63	1.41	0.45	0.86
1990	2.28	2.35	0.40	1.03

*Table 6.11 Observed and modelled damages to businesses buildings and contents (1990 values) for the January 1990 storm events in the UK. Two times the standard deviation (2*sd) in the modelled damages and the ratio of the modelled to the observed damages are also presented.*

	Observed	Modelled	2*sd	Ratio modelled/observed
Business buildings (billion €)				
Insured damages	0.24	0.19	0.04	0.78
Relative damages	0.24	0.22	0.06	0.91
Claim density	0.24	0.21	0.03	0.85
Business contents damages (million €)				
Insured damages	10.1	9.8	1.7	0.97
Relative damages	8.8	6.4	2.9	0.73
Claim density	8.8	7.9	1.7	0.89

6.2.5 Prospects under climate change

What can be expected for future storm damages under climate change in the UK?

In the section on modelling storm damage in The Netherlands it is stated that an increase of the intensity of storms (the windgust) of 2% in 25 years and 6% in 75 years is conceivable. As for The Netherlands, in the UK damages are exponentially related to windgust. This results in a dramatic increase in the modelled storm damage in the studied periods. It should be noted that the predicted changes in wind intensity (2-6%) lie well within the range of present observations; extrapolation uncertainties are limited.

The model results for two storms – October 1987 for residential buildings and January 1990 for all loss categories – are presented in Tables 6.12 and 6.13. Results for the January 1990 storm are presented in . A 20-110%, 14-68% and 9-41% increase in the insured damages to residential buildings, business buildings and business contents, respectively, would be the consequence of a 2 to 6% increase in windgust.

An increase in the number and value of the stock-at risk would also lead to an increase of the insured damages. When assuming a 0.3% annual demographic growth rate and a 2.8% annual economic growth rate, the increase in the number of the stock-at-risk would lead to an increase of the insured damages with 8% and 100% for residential buildings and businesses respectively in 25 years. When assuming the insured value of property to increase linearly with economic growth this would again lead to an increase of the insured damages with 100% for both residential buildings and businesses. However, under the normal circumstances, the increase in the number of the stock would lead to an increase in the number of insurance policies and thus in the income of the insurance industry.

Table 6.12 Increase in modelled damages to residential buildings of the October 1987 and the January 1990 storm events due to a 2-10% increase of the windgust. Two times the standard deviation in the estimates are presented below the estimates.

	Insured damages		Relative damages		Claim density	
	1987	1990	1987	1990	1987	1990
% increase insured damages						
2%	28	28	25	25	22	23
2*sd	34	19	30	20	23	12
4%	63	65	55	57	50	51
2*sd	57	32	48	33	37	20
6%	109	111	93	97	84	85
2*sd	81	45	68	46	52	27
8%	167	171	141	148	125	127
2*sd	111	61	91	61	68	36
10%	242	248	201	211	176	179
2*sd	149	82	118	80	88	46
Increase insured damages (billion €)						
2%	0.31	0.65	0.23	0.66	0.32	0.53
2*sd	0.39	0.44	0.27	0.53	0.33	0.29
4%	0.71	1.48	0.51	1.49	0.71	1.19
2*sd	0.63	0.72	0.44	0.85	0.53	0.46
6%	1.22	2.55	0.86	2.53	1.18	1.99
2*sd	0.91	1.04	0.62	1.19	0.73	0.64
8%	1.88	3.92	1.31	3.84	1.77	2.98
2*sd	1.24	1.41	0.84	1.59	0.96	0.84
10%	2.72	5.69	1.86	5.49	2.49	4.20
2*sd	1.66	1.88	1.09	2.08	1.24	1.07
Total insured damages (billion €)						
0%	1.12	2.30	0.92	2.60	1.41	2.35
2*sd	0.47	0.54	0.36	0.68	0.45	0.40
2%	1.43	2.94	1.15	3.27	1.73	2.88
2*sd	0.61	0.70	0.45	0.86	0.56	0.49
4%	1.83	3.78	1.43	4.10	2.12	3.54
2*sd	0.79	0.91	0.57	1.09	0.69	0.61
6%	2.34	4.85	1.79	5.14	2.59	4.34
2*sd	1.02	1.17	0.72	1.37	0.86	0.75
8%	3.00	6.22	2.23	6.45	3.18	5.33
2*sd	1.33	1.51	0.91	1.73	1.06	0.93
10%	3.84	7.99	2.78	8.09	3.90	6.55
2*sd	1.73	1.96	1.15	2.19	1.32	1.15

Table 6.13 Increase in modelled damages to business buildings and contents of the January 1990 storm events due to a 2-10% increase of the windgust in the UK. Two times the standard deviation in the estimates are presented below the estimates.

Increase in wind speed	Businesses (buildings)			Businesses (contents)		
	Insured damages 1990	Relative damages 1990	Claim density 1990	Insured damages 1990	Relative damages 1990	Claim density 1990
	% increase in damages			**% increase in damages**		
2%	19	18	14	12	10	9
2*sd	14	17	9	9	21	10
4%	41	38	30	26	21	19
2*sd	21	26	14	13	32	14
6%	68	63	47	41	32	30
2*sd	29	36	18	17	41	18
8%	99	91	68	58	46	43
2*sd	37	45	23	21	50	22
10%	137	125	91	78	60	56
2*sd	46	56	27	26	60	26
	Increase insured damages (billion €)			**Increase insured damages (million €)**		
2%	0.036	0.039	0.029	1.20	0.63	0.73
2*sd	0.026	0.037	0.019	0.86	1.37	0.76
4%	0.078	0.084	0.061	2.54	1.33	1.53
2*sd	0.040	0.058	0.028	1.30	2.04	1.12
6%	0.129	0.138	0.098	4.05	2.09	2.40
2*sd	0.055	0.078	0.037	1.70	2.65	1.45
8%	0.189	0.201	0.140	5.74	2.93	3.35
2*sd	0.070	0.100	0.047	2.11	3.23	1.76
10%	0.260	0.275	0.188	7.64	3.85	4.39
2*sd	0.088	0.124	0.057	2.54	3.83	2.08
	Total insured damages (billion €)			**Total insured damages (million €)**		
0%	0.190	0.220	0.207	9.84	6.44	7.87
2*sd	0.039	0.059	0.034	1.66	2.95	1.69
2%	0.225	0.259	0.235	11.03	7.07	8.59
2*sd	0.047	0.070	0.038	1.87	3.25	1.85
4%	0.268	0.305	0.268	12.38	7.77	9.39
2*sd	0.056	0.083	0.044	2.11	3.59	2.03
6%	0.318	0.358	0.305	13.88	8.53	10.26
2*sd	0.067	0.098	0.050	2.38	3.96	2.22
8%	0.378	0.421	0.347	15.58	9.37	11.21
2*sd	0.080	0.116	0.058	2.69	4.37	2.44
10%	0.449	0.495	0.395	17.48	10.29	12.26
2*sd	0.096	0.138	0.066	3.03	4.83	2.68

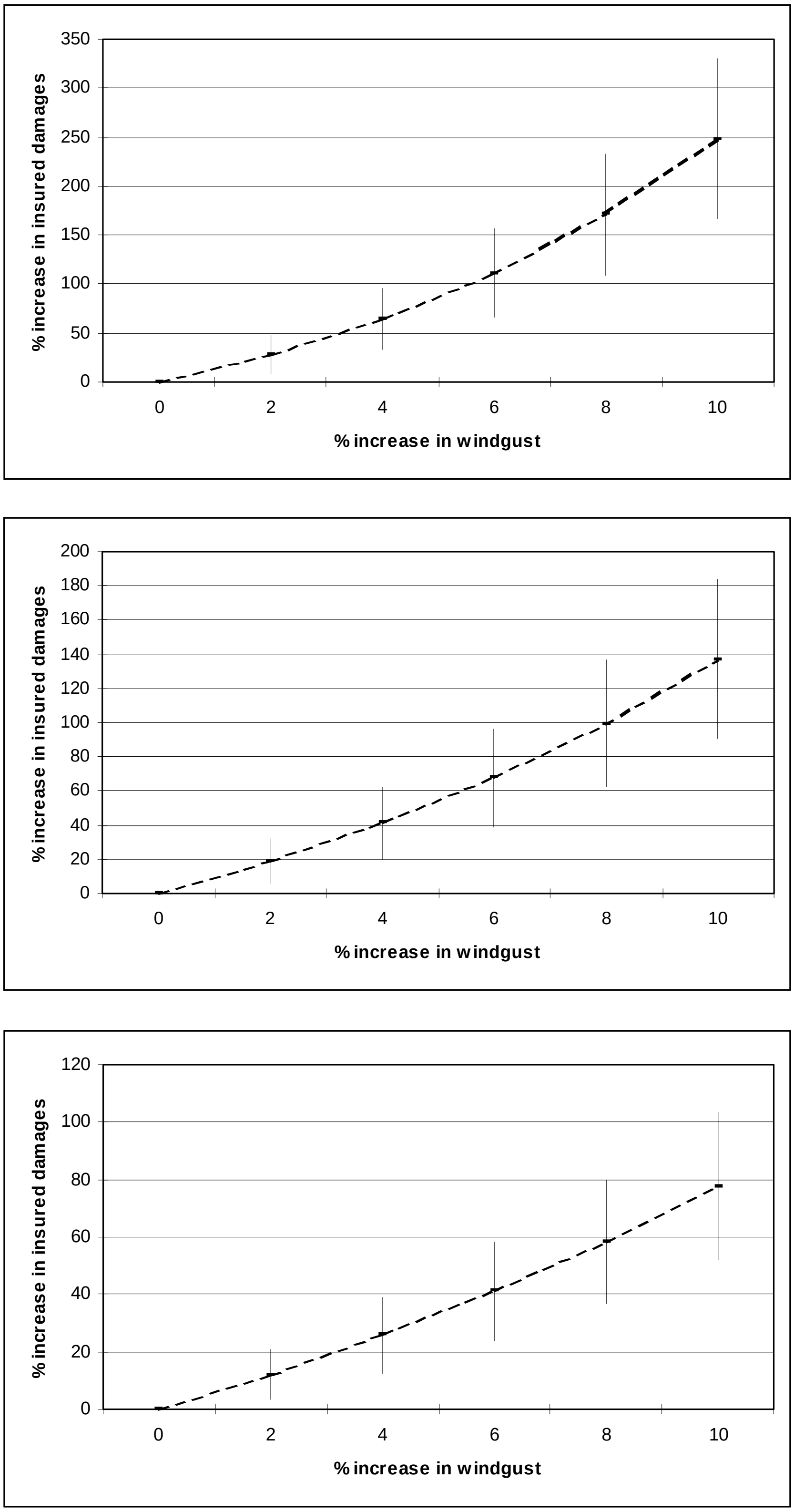


Figure 6.6 Percentage increase in insurance damage loss indicator due to a 2-10% increase in windgust for residential buildings (top), business buildings (middle) and business contents (bottom) for the January 1990 storm event in the UK.

6.3 Model comparison for The Netherlands, UK and Germany

Flechsig *et al.* (2000) present the results a storm damage analysis for the January 1990 storm in Germany. The area averaged windgust data were derived in a way comparable to the procedure for The Netherlands and the UK. The average wind speed for the German storms is 30 m/s, somewhat above the average of the Dutch storms and somewhat below the English average. In the case of The Netherlands, statistically significant different models are applicable for different ranges of wind speeds. The storm damage data represent the average of the insurance companies that have re-insurance with Munich Re. The storm damage model applied in this German analysis is somewhat simpler than the models found in this analysis:

$$\ln (LI_{i,t}) = \alpha\, (\hat{V}_{max})_{i,t} + C \qquad (6.5)$$

where:

$LI_{i,t}$	=	loss indicator, that is, insured damage ID (in €) or claim density CD (in ‰) for residential buildings or businesses in area *i* for storm event *t*;
$\hat{V}_{max;i,t}$	=	modelled windgust in area *i* for storm event *t*;
c	=	constant;
α	=	coefficient;
i	=	postal code area number; and
t	=	storm event number.

To compare the Dutch, the UK and the German models, we estimated Flechsig's model for the Dutch and UK data. The results are presented in Tables 6.14 and 6.15. The results from the German report are reproduced in Table 6.16, using their "all zones" model. As observed in the more elaborate model exercise for The Netherlands (Section 6.1.4), the model fits for low wind speeds are very poor. Both the models for the split and the total data sets are presented in Table 6.14.

Table 6.14 Estimated parameter values of the exponential relation between insured storm damage for private residential buildings and business buildings for The Netherlands. The model results for both the total data set (all $\hat{V}_{max}$) and the data sets split for the higher and lower wind speeds are presented.

Parameter	Coeff.	Std. E	t-Stat.	Coeff.	Std. E	t-Stat.	Coeff.	Std. E	t-Stat.
Residential buildings	**All $\hat{V}_{max}$** N= 856			**$\hat{V}_{max}$< 33.5 m/s** N=704			**$\hat{V}_{max}$> 33.5 m/s** N=152		
C – constant	0.64	0.25	2.5	3.60	0.37	9.6	1.65	1.57	1.1
α - wind speed	0.363	0.009	39.8	0.241	0.014	16.8	0.354	0.043	8.1
R^2	0.65			0.29			0.31		
LL	-1493			-1214			-203		
F-stat.	1588			280.6			66.4		
Businesses (buildings)	**All $\hat{V}_{max}$** N= 593			**$\hat{V}_{max}$ < 26.4 m/s** N= 196			**$\hat{V}_{max}$ > 26.4 m/s** N=397		
C – constant	0.21	0.35	0.61	8.09	1.02	7.9	-3.66	0.52	-7.0
α - wind speed	0.348	0.012	29.7	0.031	0.042	0.73	0.466	0.016	28.6
R^2	0.60			0.003			0.67		
LL	-1051			-332.7			-661.9		
F-stat.	883.1			0.531			817.7		

Table 6.15 Estimated parameter values of the exponential relation between insured storm damage (ID), relative damages (RD) and CD (claim density) for private residential buildings, businesses and businesses contents for the UK.

	ID			RD			CD		
Parameter	Coeff.	Std. E	t-Stat.	Coeff.	Std. E	t-Stat.	Coeff.	Std. E	t-Stat.
Residential buildings	**N=228**			**N=230**			**N=226**		
C – constant	4.37	0.30	14.7	-10.82	0.25	-43.9	-4.90	0.18	-27.6
α - wind speed	0.325	0.009	35.6	0.287	0.0076	37.7	0.260	0.0054	47.8
R^2	0.85			0.86			0.91		
LL	-326.6			-288.6			-203.1		
F-stat.	1270.5			1421			2288		
Businesses (buildings)	**N=113**			**N=114**			**N=113**		
C – constant	4.05	0.57	7.0	-6.96	0.46	-15.0	-1.10	0.32	-3.5
α - wind speed	0.267	0.016	16.7	0.205	0.013	15.8	0.164	0.009	18.6
R^2	0.72			0.69			0.76		
LL	-149.1			-127.7			-84.1		
F-stat.	279.0			250.8			346.6		
Businesses (contents)	**N=82**			**N=83**			**N=83**		
C – constant	5.31	0.77	5.8	-6.1	1.5	-13.2	-1.16	0.64	-1.8
α - wind speed	0.162	0.021	7.8	0.121	0.041	3.0	0.093	0.017	5.3
R^2	0.43			0.099			0.26		
LL	-93.7			-151.7			-83.3		
F-stat.	60.2			8.8			28.5		

Table 6.16 Estimated parameter values of the exponential model for relative damages RD and claim density CD for private residential buildings and business buildings for Germany.

	RD		CD	
Parameter	Coeff.	Std. Err.	Coeff.	Std. Err.
Residential buildings	**N=61**		**N=61**	
C – constant	-10.73	0.76	-6.74	0.65
α - wind speed	0.283	0.025	0.281	0.021
R^2	0.69		0.75	
F-stat.	105.1		174.3	
Businesses (buildings)	**N=59**		**N=59**	
C – constant	-12.8	1.0	-7.1	0.8
α - wind speed	0.354	0.031	0.284	0.025
R^2	0.69		0.69	
F-stat.	129.1		129.0	

Source: Flechsig *et al.* (2000) and Flechsig (personal communication).

For residential buildings, the estimated wind speed parameters for the UK and Germany are not statistically significant. The estimated wind speed parameters for The Netherlands (high wind speeds; $\hat{V}_{max} > 33.5$ m/s) and the UK are not statistically significant. The estimated wind speed parameters for The Netherlands (all wind speeds) and the UK are only just significantly different. Thus, high winds have the same impact on residential buildings in the UK, in The Netherlands, and in Germany.

Although the wind parameters do not significantly differ, relative vulnerability is not necessarily the same. Because of the curvature of the relationship between wind speed and damage, a uniform, relative increase in wind speeds would imply a relatively higher increase in areas with higher winds to start with. In Figure 6.6, the average maximum windgust of the storms analysed for The Netherlands (10 storm events) and the UK (3 storm events) are presented. Wieringa and Rijkoort (1983) and Christofides *et al.* (1992) found similar patterns in the spatial change of the maximum sustained windgusts in The Netherlands and the UK, respectively. Unfortunately, no map of average windgust for the storm events analysed for Germany was available. Munich Re (1993) shows that the highest windgusts were sustained in the western and southern part of Germany during the 1990 storm events. Thus, the relative increase in the damages due to climate change decreases further inland (The Netherlands and Germany) and further north (UK). The number of houses is also different in different locations. See Figure 6.7 and Figure 6.8. Broadly, more houses are found at places with higher winds, amplifying the differences in vulnerability.

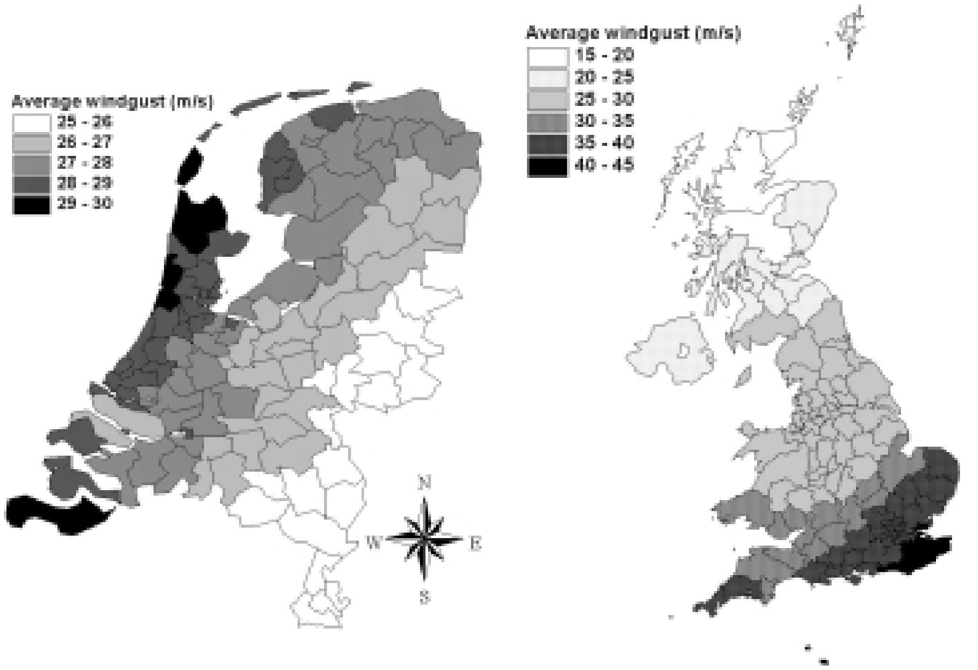


Figure 6.6 Average windgust due to analysed storm in The Netherlands and the UK.

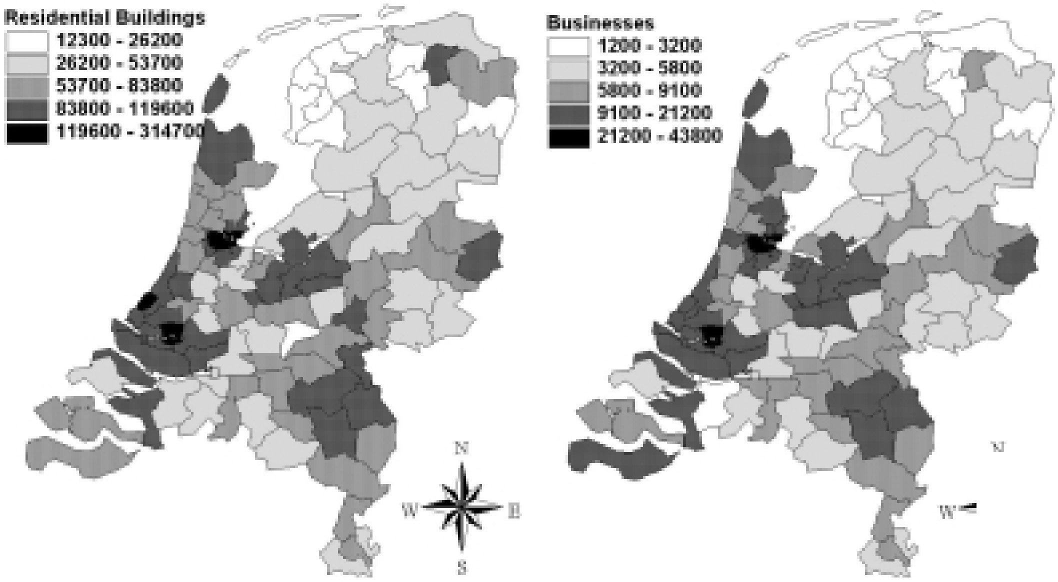


Figure 6.7 The number of residential buildings (left) and businesses (right) in The Netherlands in 1994.

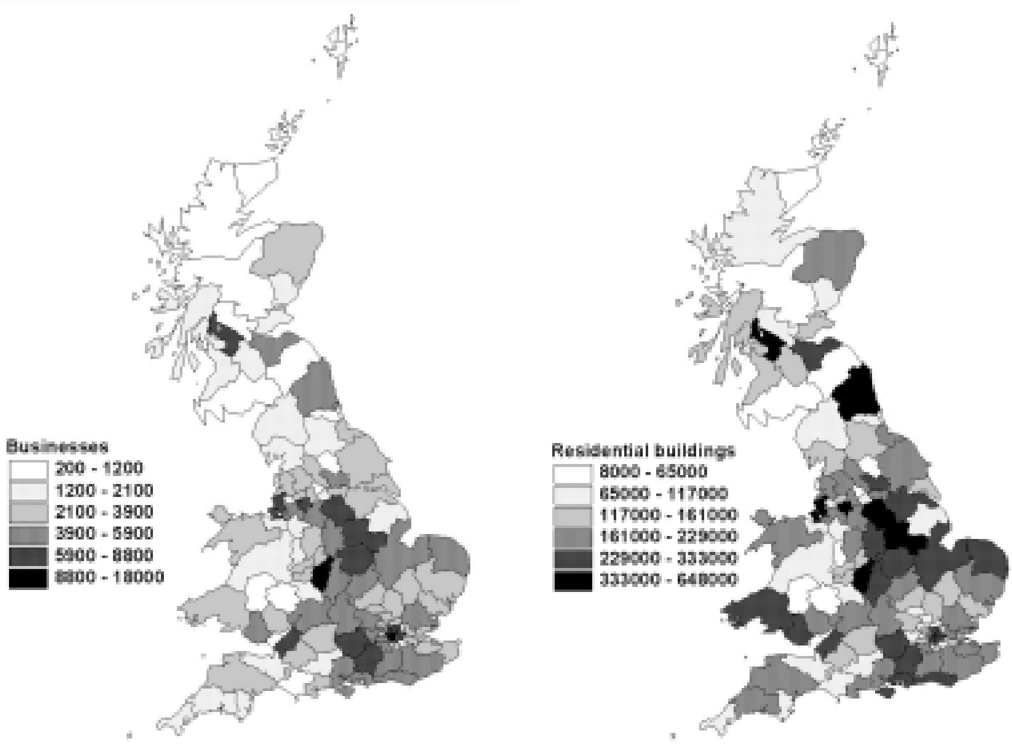


Figure 6.8 The number of residential buildings (left) and businesses (right) in the UK in 1990.

For businesses, the estimated wind speed parameters are significantly different.[18] A possible explanation is that the different types of businesses were analysed in the three countries (all businesses with an insured value smaller that 4.5 million Euro for The Netherlands; all rented businesses in the UK; all businesses with re-insurance through Munich Re in Germany).

6.4 Conclusions

In order to estimate damage from future storms in The Netherlands and the UK, storm-damage models for residential and business buildings and contents have been developed. For the Dutch and the UK analyses, meteorological characteristics and insurance data of ten and 3 storm events in the period 1987-1992 were obtained.

In this study, a geographically explicit storm damage model, linking meteorological and damage data on a two-digit postal code level, is used. The model results confirm that storm damage is very sensitive to the wind speed. An exponential function is found to fit the data best. Furthermore, the windgust gives a better model fit than the maximum hourly average wind speed.

In this analysis, the influence of a 0-10% increase in the maximum gust speed is analysed. A climate change related increase in the windgust of 2% in 25 years is held con-

[18] Except between the Netherlands (low wind speeds) and the UK.

ceivable. Scenario analysis with these geographically-explicit storm model shows that a 2% increase in the windgust could lead to an increase of insured damages to residential buildings by around 20-30%. For business buildings the increase could be between 10 and 45%. A 6% increase in the windgust could even lead to an increase of insured damages to residential buildings and business building of around 80-110% and 50-200% respectively. These increases do not include the effects of demographic and economic growth. For contents of business buildings, the model fit (for the UK only) is very poor. If this model is used in a similar scenario analysis, the damages could increase with 10-40% for a 2-6% increase in the windgust. From the German WISE report, it can be concluded that similar percentage damage increases for residential and business buildings are modelled for Germany as presented here. The results indicate that, at similar wind speeds, the vulnerability of residential buildings to storms are not too different in The Netherlands, the UK and Germany although the type of buildings is very different. For businesses, the differences between the estimated wind speed parameters in the models for all loss parameters are statistically significant. The different types of businesses analysed in the countries could explain for the differences. It should be noted that scenario analyses performed with these models are very speculative as the data set for especially the UK is very limited, the possible changes in insurance cover, developments in building standards and building materials, the behaviour of policy holders and governments and because climate change uncertainties are large.

Finally, Dorland *et al.* (1999) argue that little potential seems to exist for reducing the vulnerability to storms in The Netherlands. This probably also holds for the UK and Germany. One possible way of decreasing vulnerability would be to increase the building standards. However, this could lead to unaffordable increases in the prices of buildings. In the mean time (re) insurers look for options such as withdrawal from broad coverage and raising deductibles to minimise their losses. Overall it can be argued that more attention should be given to planning for disaster relief at central and local government levels, and the development of coping strategies.

Acknowledgement

The authors would like to thank Dr. A. F. Dlugolecki and Dr. D. Crichton of General Accident, Perth, UK, for providing insurance damage data for the UK. We would also like to acknowledge Mrs. Drs. M. van Kraaij and Drs. J. de Snoo of the Centre for Insurance Statistics (CVS), the Hague, The Netherlands for providing insurance damage data for The Netherlands.

7. Perception Study

Kees Dorland[19] and Richard S.J. Tol[20]

7.1 Introduction

A funny thing about climate change impact research is that it is so dominated by models. Data, of course, inform the models, but only a few studies look at the data directly, let alone gather new data. This chapter is an exception. It presents the results of the Dutch component of a four-country survey into people's perceptions about extreme weather, climate change, and adaptation.

7.2 Methods

The survey was developed by a team of researchers from the University of East Anglia, Norwich, United Kingdom, the Potsdam Institute for Climate Impacts Research, Potsdam, Germany, the Fondazione Eni Enrico Mattei, Milan, Italy, and the Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands. A draft version of the survey was pre-tested among employees of these four institutes. The results were discussed by the four team, leading to a substantial revision. The final version of the survey can be found in the Appendix. Similar surveys were conducted in the UK, Germany and Italy.

Mid October, 1,000 copies of the questionnaire were mailed to randomly selected addresses in The Netherlands. The questionnaires were printed on plain paper. No gifts were included, or rewards promised. A postage-free return envelope was enclosed. The questionnaires were accompanied by a letter of Professor Pier Vellinga, director of IVM, explaining the purpose and context of the survey (cf. Appendix 1.2). Late December, 223 questionnaires had been returned. The spread in the answers is such that with 200-odd observations a reasonably informed picture emerges.[21]

7.3 Perceptions of hot and dry summers

Figure 7.1 displays the results of the question whether people generally prefer unusual hot over cold whether. A large number (45%) do, although a little over a quarter rather have it the other way around. About a third does not care or know.

Figure 7.2 displays whether specific aspects of hot and dry summers are valued positively or negatively. A composite valuation is also displayed. The composite is defined as the sum of the scores per aspect (displayed in Figure 7.2) times the fraction of respondents that considered this aspect to be the most important. People positively value hot

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21 Had the spread been larger, a second mailing would have been sent out.

and dry summers. Negative aspects, such as work, commute and air pollution, are not that important.

Figure 7.3 displays the distribution of appreciation for the most important aspects, in order of importance: comfort, leisure, health, and work. Although the impact of the hot and dry summers on the first three is generally considered to be positive, a substantial number of people disagrees. This is also the case for work, which is generally considered negative.

Figure 7.4 displays the impact of hot and dry summers on respondents' moods. Mood can be considered as an alternative composite evaluation. Figure 6.4 confirms the overall evaluation of Figure 7.2 and Figure 7.3: People like hot and dry weather.

Figure 7.5 displays the perceived impact of hot and dry summers of the country as a whole. Here, the impact is negative, except for leisure and economy. The latter is strange because it incorporates many of the other national aspects.

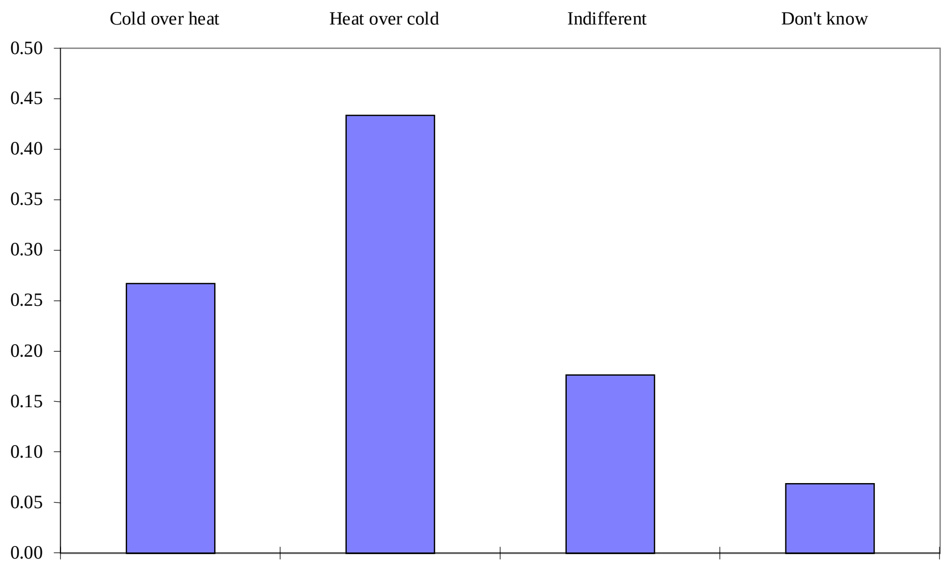

Figure 7.1 General preferences of the Dutch to weather. The bars display the fraction of respondents who, for instance, prefer cold over hot weather.

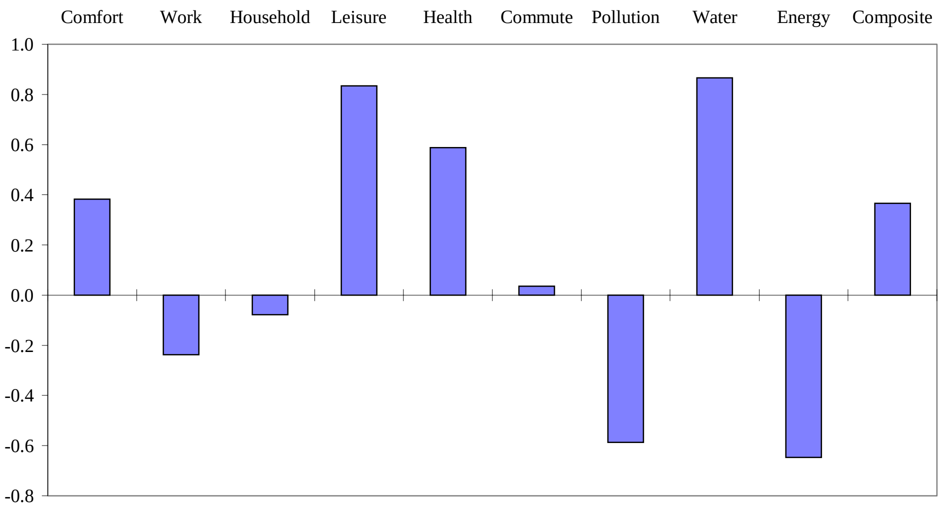

Figure 7.2 Positive and negative aspects of hot and dry summers. Individuals could score these aspects on a scale of -2 to 2. The bars display the average score.

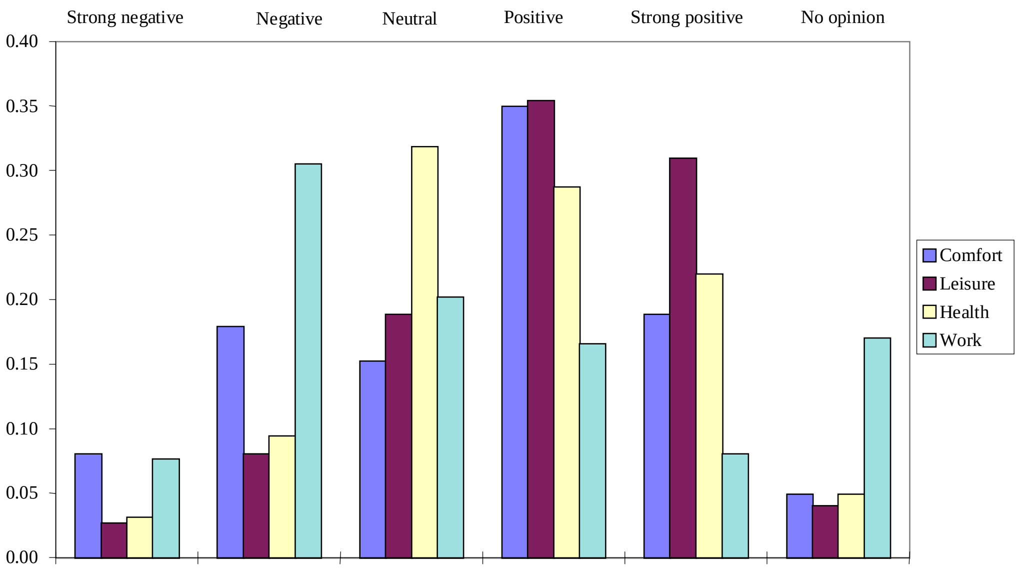

Figure 7.3 Specific aspects of hot and dry summers. The bars display the fraction of respondents who, for instance, classified the effect of hot weather on comfort as strongly negative.

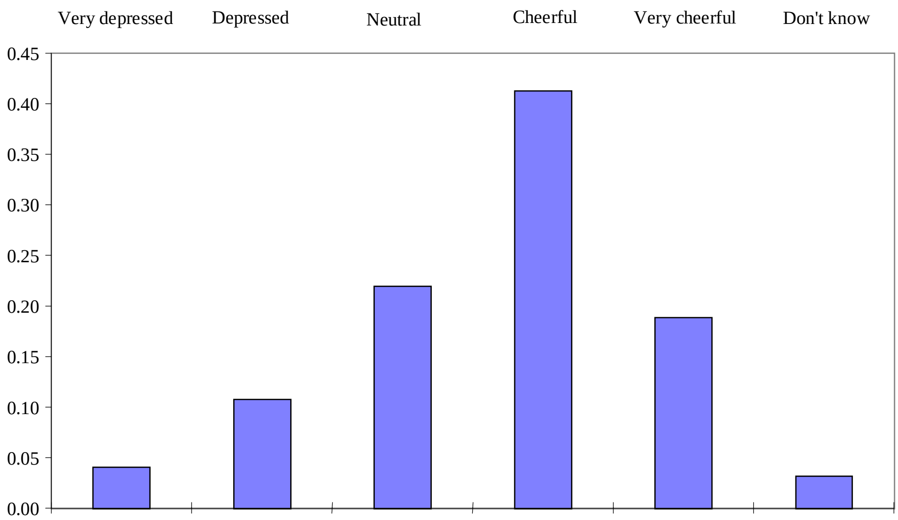

Figure 7.4 Moods in hot and dry summers. The bars display the fraction of respondents who, for instance, called themselves very depressed during hot weather.

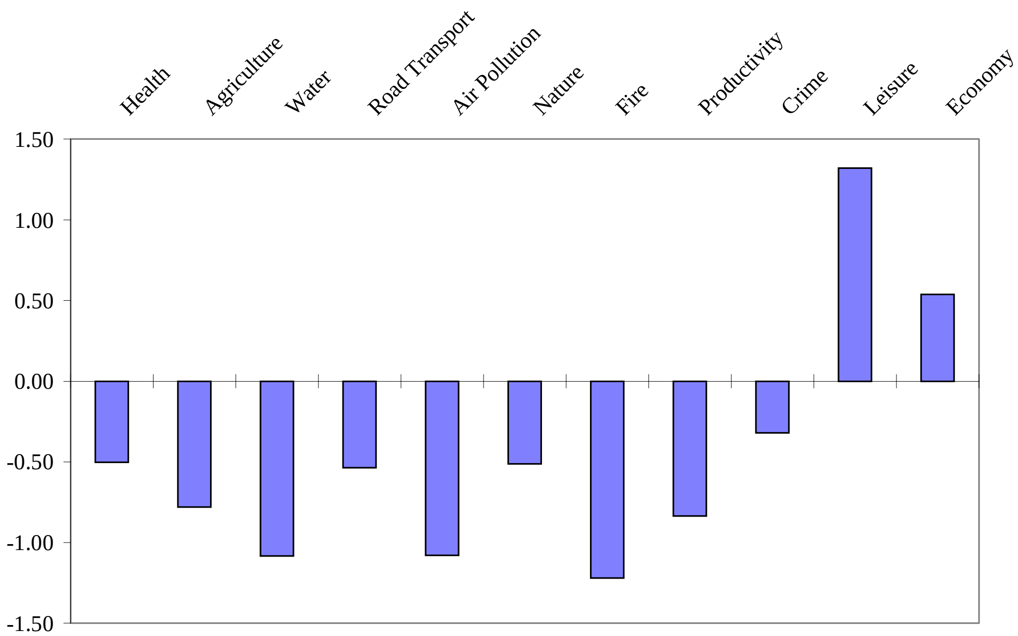

Figure 7.5 Specific aspects of hot and dry summers for the whole country. Individuals could score the impact of hot weather on a scale of -2 to 2. The bars display the average score.

7.4 Perceptions of mild winters

Figure 7.6 displays the evaluation of the respondents of mild winters. Generally, people prefer mild winters, with an exception for winter sports, winter atmosphere, and plagues. The composite evaluation (defined as above) is also positive.

Figure 7.7 displays the spread in answers for the four most important aspects, viz. comfort, health, atmosphere and commute. Like with hot and dry summers, the spread is large.

Figure 7.8 integrates respondents' evaluation into a single index, namely their moods. Overall, people feel better when winters are mild.

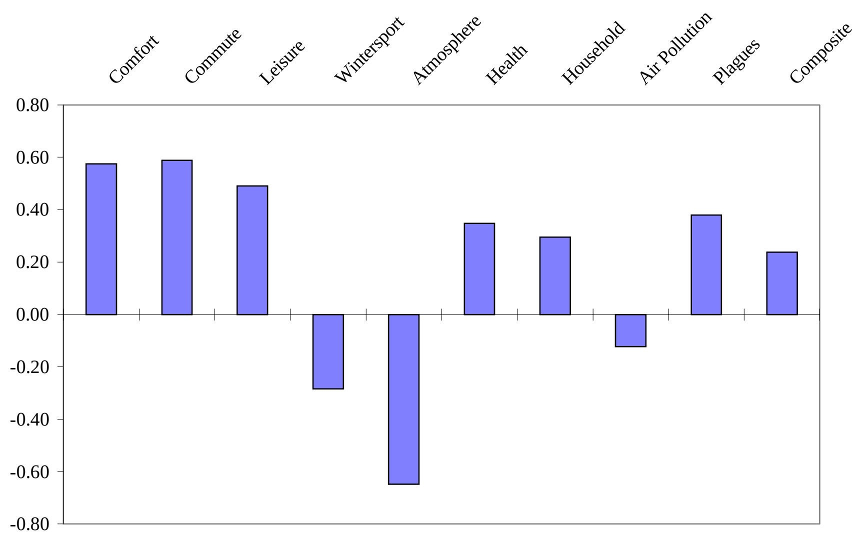

Figure 7.6 Positive and negative aspects of mild winters. Individuals could score the impacts of mild winters on a scale of -2 to 2. The bars display the average score.

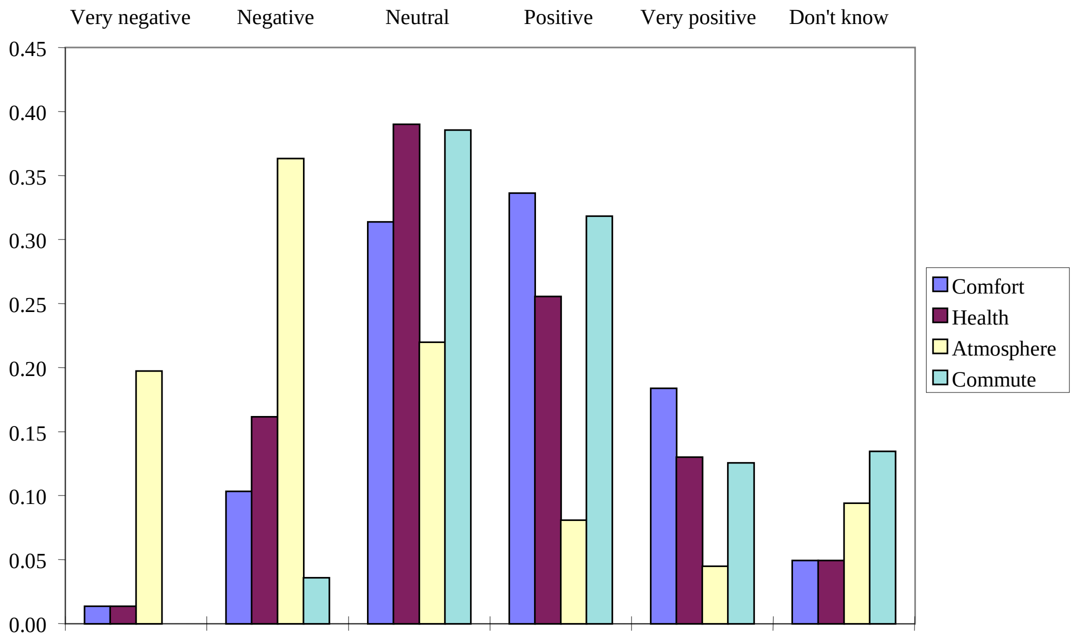

Figure 7.7 Specific aspects of mild winters. The bars display the fraction of respodents who classified, for instance, the impact of mild winters on their comfort as very negative.

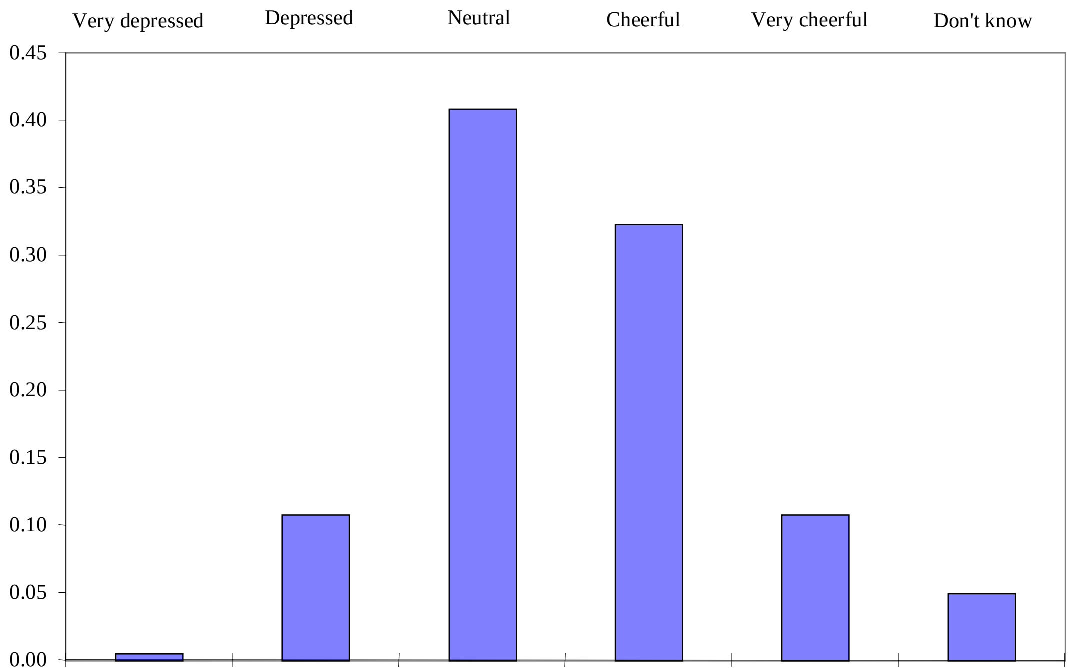

Figure 7.8 Moods in mild winters. The bars display the fraction of respondents who classified their mood in mild winters as, for instance, very depressed.

7.5 Perceptions of climate change

When asked for their evaluation of a possible increase in the number of hot and dry summers, respondents gave ambiguous answers. Figure 7.9 displays the results for various aspects. Some 15% answered that there would be a positive impact on them, mentioning leisure, life-style, energy use, other people's behaviour and health. Also 15% answered in the negative, mentioning air pollution, water consumption, health, other people's behaviour, and crime.

Figure 7.10 displays the respondent's overall evaluation. A clear majority finds an increase in hot and dry summer conditions pleasing, but a majority also finds this alarming. The latter result is less strong, however. Still, the ambiguity about an increase in hot and dry conditions contrasts with the clear preference that respondents expressed for such conditions.

Figure 7.11 displays the results for broader questions, namely whether people find climate change likely and desirable. A majority thinks that climate will change, but the number of indecisive answers is large. Climate change is generally considered to be undesirable. Although respondents undoubtedly considered more than just hot and dry summers, this results adds to the ambiguity of the above.

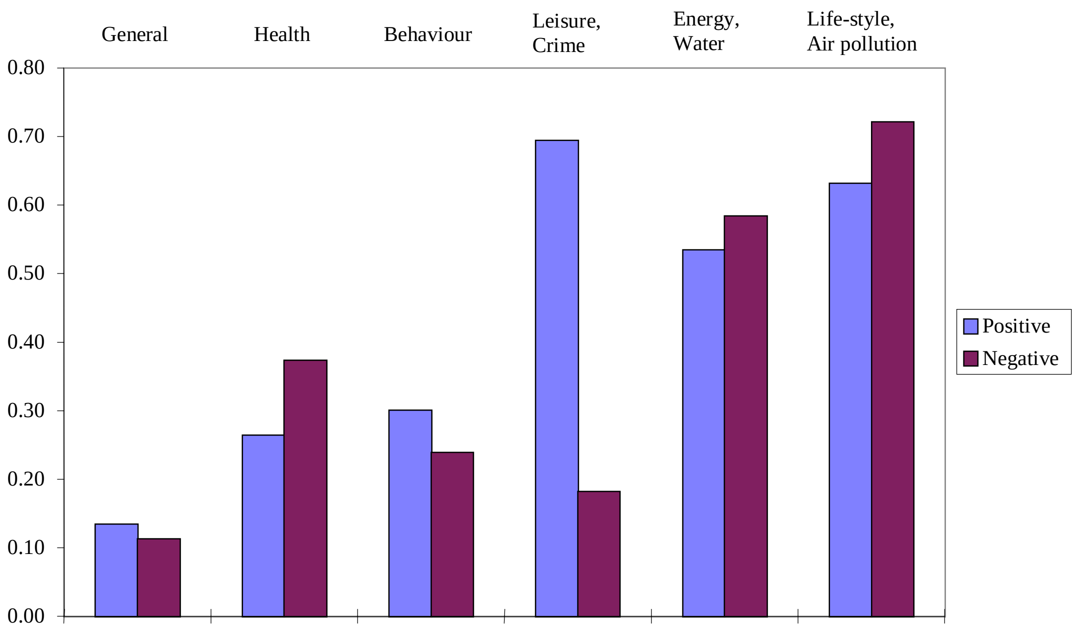

Figure 7.9 Evaluation of a possible increase in hot and dry summers. The bars display the number of respondents that classified, for example, the general impacts of hot weather as positive.

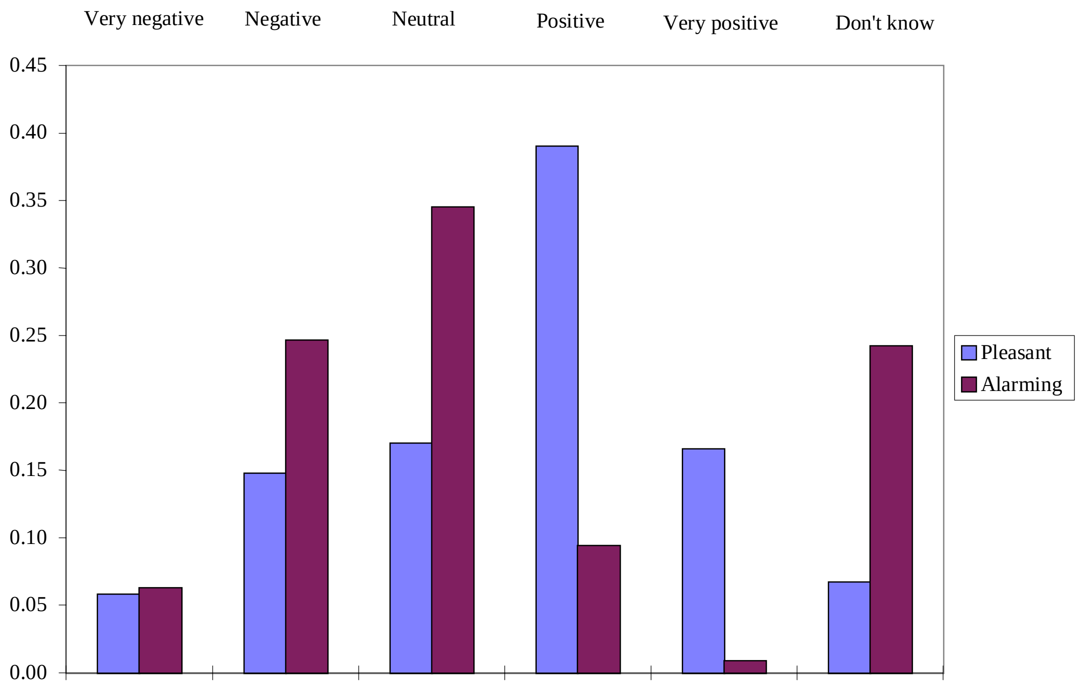

Figure 7.10 *Evaluation of a possible increase in heat. The bars indicate the fraction of respondents that classified, for example, the prospect of increased heat as very pleasant.*

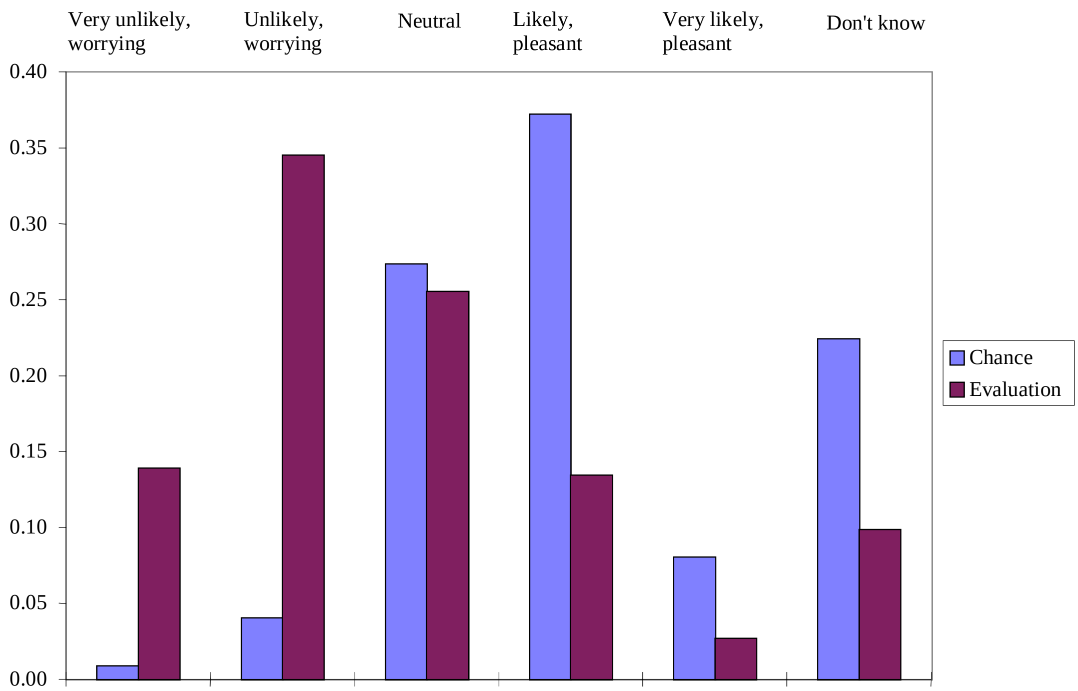

Figure 7.11 *Prospects of climate change. The bars indicate the fraction of respondents that classified, for example, the chance of climate change as very unlikely.*

7.6 Adaptation

Figure 7.12 to Figure 7.15 display whether respondents think they alter their behaviour during periods of hot and dry weather. Figure 7.12 reveals that people use different modes of transport. Figure 7.13 shows that people consume different services. In both cases, the obvious tendency is towards the outdoors. Figure 7.14 shows that people do take more day trips during hot and dry summers, that short holidays are substantially less responsive, and that most people do not change their plans for their main vacations. The majority of those that *did* change their plans decided to stay home or in The Netherlands. The analysis in Section 2.1 suggests that people do change their holiday plans for the next year, and that more people stay at home during hot summers. Figure 7.15 also shows that the time or duration of the vacations is not much influenced by hot and dry summer weather, probably because these factors are often fixed long before summer.

Figure 7.16 displays the answers to the question whether people permanently change their behaviour. A surprisingly large number answered that their behaviour has been permanently altered because of one hot and dry summer in the past. More time outdoors, increased avoidance of the sun, higher fruit consumption, and more driving are mentioned most. The last is inconsistent with the result of Figure 7.12 that respondents use their cars *less* during hot weather. If climate were to change, more people would permanently change their behaviour, particularly during holidays.

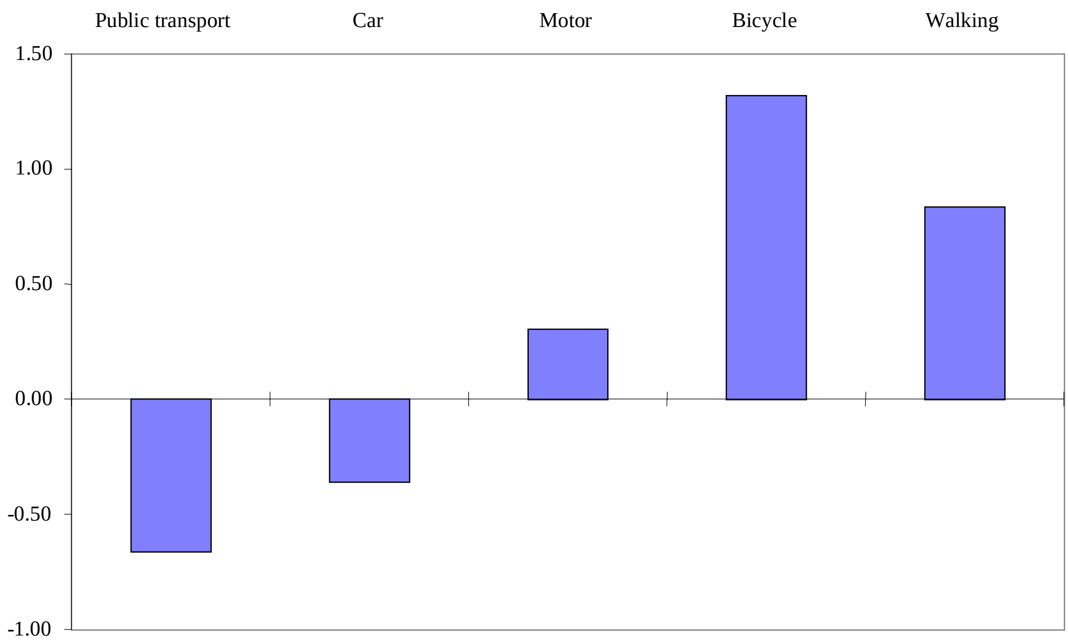

Figure 7.12 Adaptation of transport. Interviewees were asked to classify their use of transport modes on a scale of much less (-2) to much more (2). The bars indicate the average response.

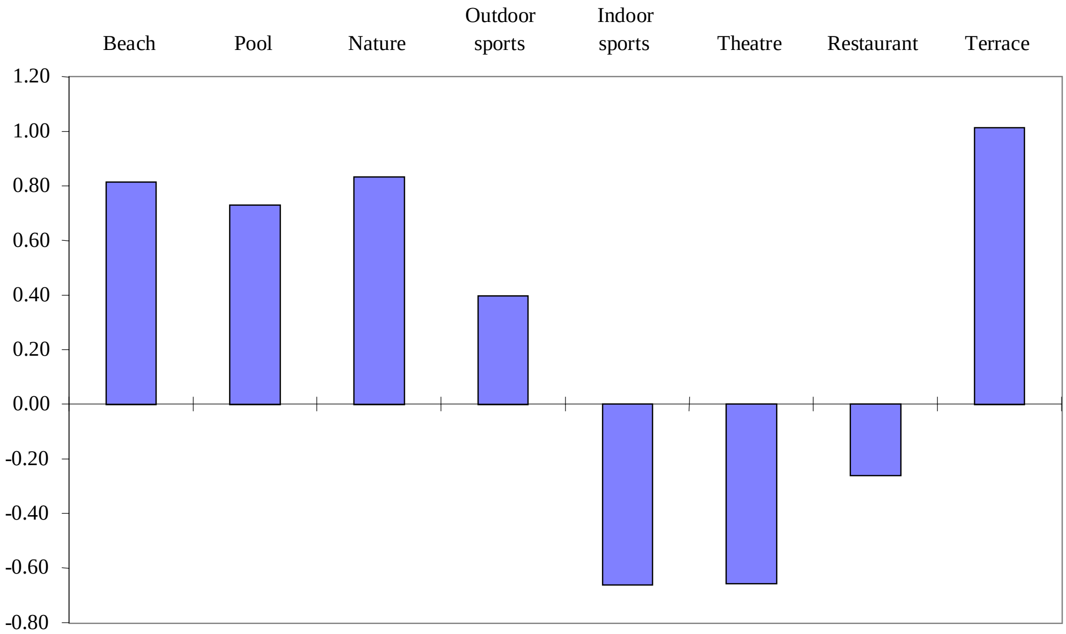

Figure 7.13 *Transient adaptation of general behaviour. Interviewees were asked to classify their use of facilities modes on a scale of much less (-2) to much more (2). The bars indicate the average response.*

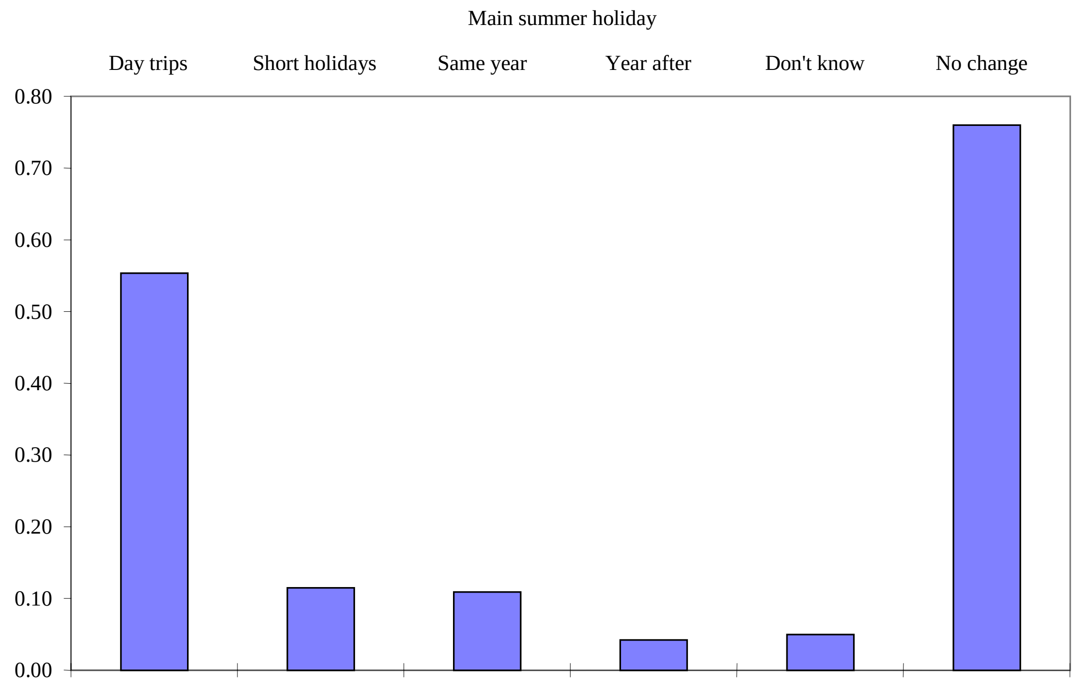

Figure 7.14 *Transient adaptation of holiday behaviour. Interviewees were asked to classify their consumption of holiday types on a scale of much less (-2) to much more (2). The bars indicate the average response.*

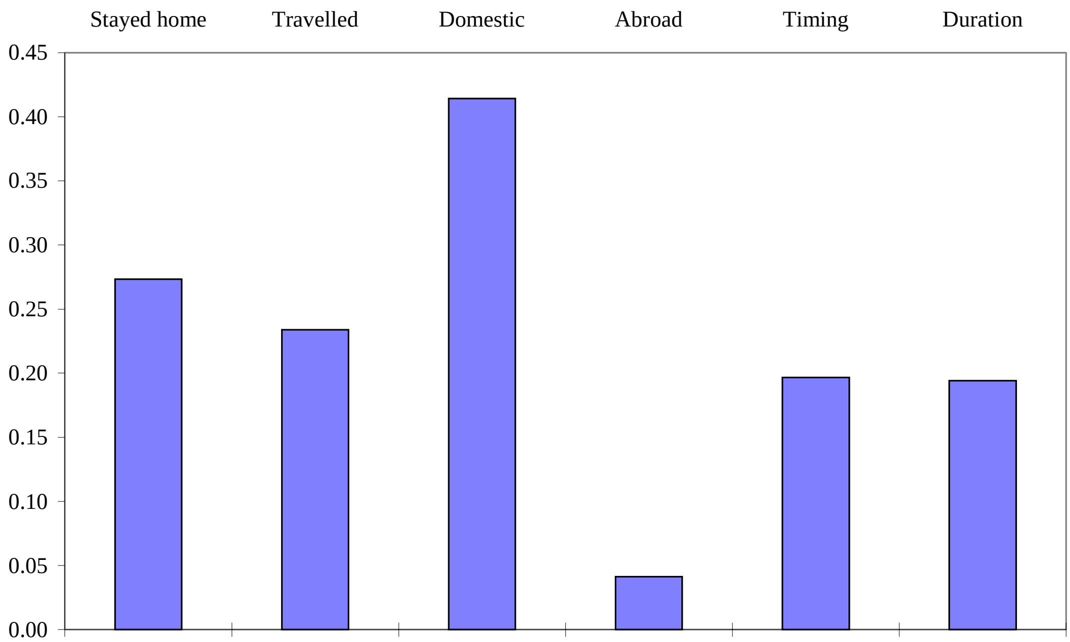

Figure 7.15 Permanent adaptation of holiday behaviour. Interviewees were asked to classify their use of holiday types on a scale of much less (-2) to much more (2). The bars indicate the average response.

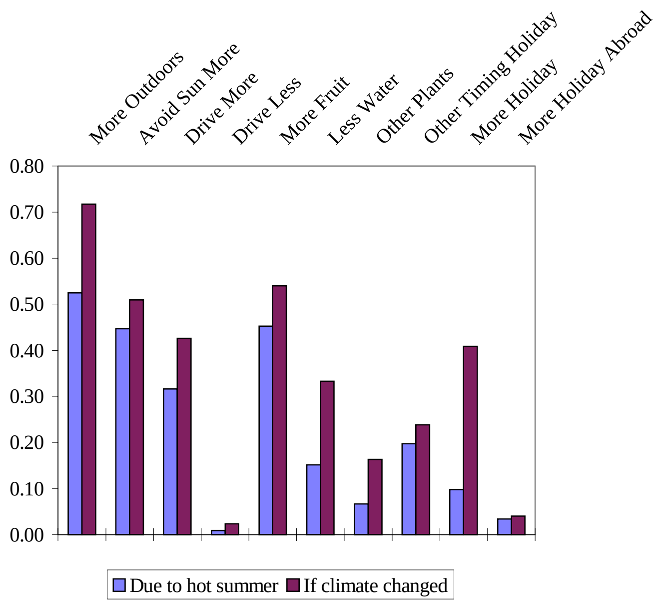

Figure 7.16 Permanent adaptation of general behaviour. Interviewees were asked to classify the change in their activities on a scale of much less (-2) to much more (2). The bars indicate the average response.

7.7 Perceptions of temperature

People were also asked to indicate which summer they thought was hottest, and which winter mildest. Figure 7.17 displays the results for summer, and compares them to the observed temperature. People's memories are clearly short-lived. 1998 is remembered as a cool summer, and 1997 as a warm one. However, 1996 is often mentioned, although it was cool. 1994 and 1995, at least as hot as 1997, are mentioned less often. Two respondents mentioned years before 1990. One was correct in naming 1976 hot (18.4°C), the other incorrectly mentioned 1973 (16.9°C).

Figure 7.18 shows the results for winter. The mild winter of 1998 is clearly remembered. However, 1996 and 1997 are often mentioned as well, although these winters were a lot colder. The mild winters of 1989, 1990, and even 1995 are largely forgotten. No one mentioned winters before 1990. The response rate to these questions was clearly lower (about 75%) than that to most other questions.

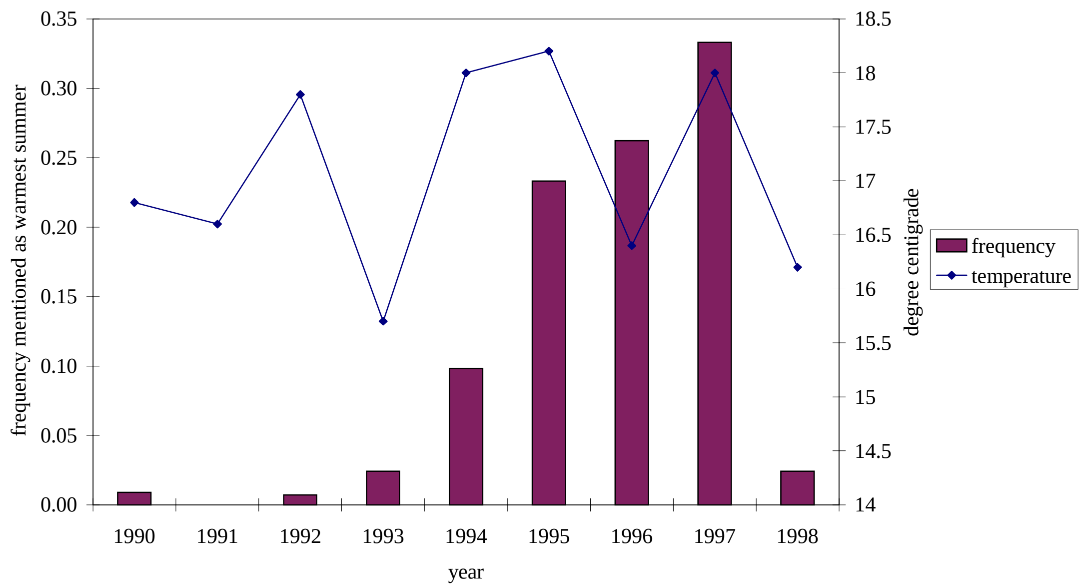

Figure 7.17 Real and perceived summer temperatures. The bars indicate the fraction of respondents that singled out a particular year as very hot.

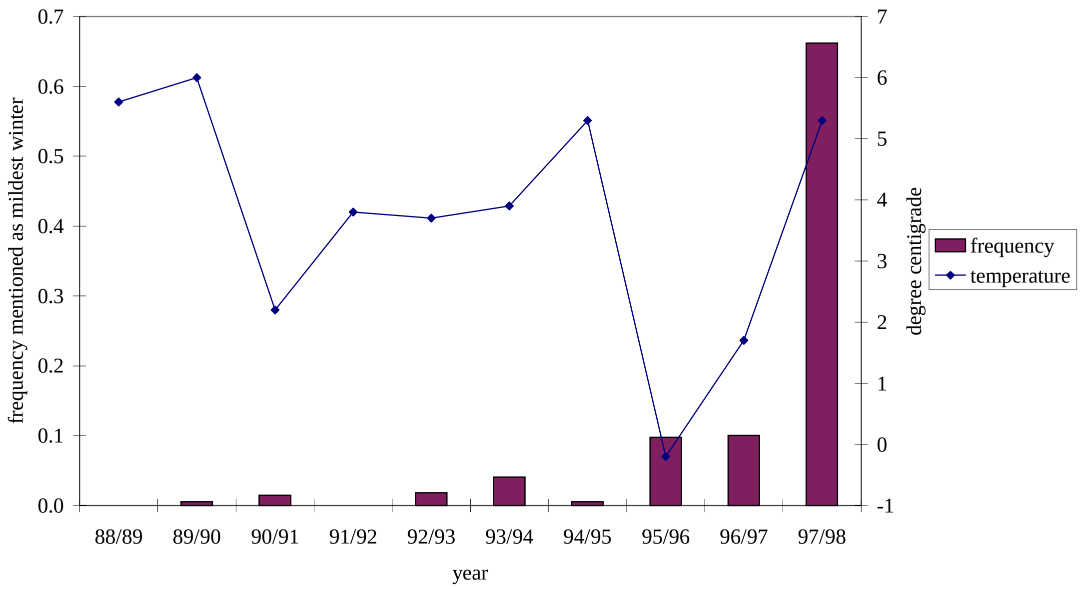

Figure 7.18 Real and perceived winter temperature. The bars indicate the fraction of respondents that singled out a particular year as very cold.

7.8 Conclusions

People in The Netherlands like hot and dry summers and mild winters. They are undecided whether they want more hot and dry summers, and do not seem to like climate change. Changes in behaviour are there, and as expected. People do not seem able to remember the weather well for a long time.

8. Discussion and Conclusion

Richard S.J. Tol[22], Kees Dorland[23], Wietze Lise[23] and Alexander A. Olsthoorn[23]

In general, we find that weather variability has a significant but small influence on the selected sectors. The economic impacts are equally small. See Table 8.1.

The findings cannot be readily interpreted in a climate change context. The reason is twofold. Firstly, looking at weather variability, we only consider short-term adaptation. Long-term adaptation (adjustments in the capital stock, changes in management practices) is crucially important in assessing the implications of climate change. Secondly, we rely on 'black-box' statistical techniques. Not modelling any process detail, reliable extrapolation is hard.

The statistical analysis and the survey contradict each other on tourism. The statistical analysis suggests that people (a) book more foreign holidays the year after a hot summer, and (b) reduce the number of holidays during a hot summer. The survey suggests that people are unaware of this. The survey suggests that the number of day trips increases during hot weather, a factor unaccounted for in the statistical analysis.

The survey and the statistical analyses agree that weather variability is not very important to the economy and population of The Netherlands. This reflects the desire and ability of modern day society to minimise its dependence on the vagaries of the weather. It also reflects what little a role basic commodities play in current economies.

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[23] Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands

Table 8.1 Sector-wise weather impact analyses.

Sector	Series considered	Impacts	Change in sensitivity/ evidence of adaptation	Valuation
Agriculture	Wheat	Yields are higher after a warm winter and a wet summer (all wheat). Yields are higher after a wet winter, a cool summer, and (perhaps) a warm summer in the previous year (winter wheat). Yields are higher after a wet winter (summer wheat).	No significant effect.	N/a
	Sugar beet	Yields are higher after a dry and warm winter.	Price falls in current year, acreage in following year.	N/a
	Strawberry	No interpretable weather effect.	No significant effect.	0
	Apple	No significant weather effect.	No significant effect.	0
	Pig, piglet	No significant, interpretable weather effect.	No significant effect.	0
	Potatoes	Yields are higher after a cool weather, in summer (clay potatoes, industrial potatoes), in winter (consumption potatoes), or both (sand potatoes).	Acreage of consumption potatoes falls in following year.	N/a
Fire	Built environment	No interpretable results.	No interpretable results.	0
	Nature	Fires are more frequent and more extensive fires during dry summers.	Fires become less frequent over time, because of a decline in natural area and campaigns to reduce the number of fires.	N/a
Health	N/a	N/a	N/a	N/a
Water	Domestic water consumption	Domestic water consumption falls during cool and wet weather	Average water consumption increases with the length of a hot or dry spell.	1%/ºC ≈ 1 cent/ºC/person /day
Energy	Gas	Domestic and industrial gas consumption falls during warm winters.	Not found.	3.8%/ºC (domestic); 7 cent/ºC/person /day 0.9%/ºC (industrial)
	Electricity	No interpretable weather effect.	N/a	0
Tourism	People on holiday	The number of people on taken perhaps decreases the year after a hot summer.	Not found.	N/a
	Foreign visitors	There are more foreign visitors during a hot summer.	Not found.	N/a

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Appendix I. Perception Study

A1.1. Survey

WISE ENQUETE

-Amsterdam, 10 September 1998 -

1. Wat is vindt U van ongewoon weer in Nederland?

(Een hokje aankruisen)

A	Ik geef de voorkeur aan ongewoon koud weer boven ongewoon heet weer	☐
B	Ik geef de voorkeur aan ongewoon heet weer boven ongewoon koud weer	☐
C	Ik merk bijna niets van ongewoon weer	☐
D	Geen mening	☐

U kunt zich vast een hete en droge zomer herinneren in de afgelopen paar jaar. Denkt U aan deze zomer bij het beantwoorden van de volgende vragen.

2. *Hoe werd Uw dagelijks leven beinvloed door deze hete en droge zomer?*

(Een hokje aankruisen per vraag)

negatief	*positief*					*Weet niet/ N.v.t*
A Persoonlijk comfort	-2	-1	0	1	2	☐
B Activiteiten op het of school	-2	-1	0	1	2	☐
C Huishouden	-2	-1	0	1	2	☐
D Vrijetijdsactiviteiten	-2	-1	0	1	2	☐
E Gezondheid	-2	-1	0	1	2	☐

	negatief				*positief*	*Weet niet/ N.v.t*
F Dagelijkse reizen	-2	-1	0	1	2	
G Luchtverontreiniging	-2	-1	0	1	2	
	veel minder				*veel meer*	
H Watergebruik	-2	-1	0	1	2	
	veel minder				*veel meer*	
I Energiegebruik thuis	-2	-1	0	1	2	

J. Anders (vertel alstublieft wat)*:*

…………………………	-2	-1	0	1	2

3. Welke van de effecten van Vraag 2 was het <u>belangrijkst</u> voor **U**?

(de letter van vraag 2) ☐

4. Hoe voelt U zich als het erg heet is?

erg somber				*erg blij*	*Weet niet*
-2	-1	0	1	2	

5. Bent U meer of minder gebruik gaan maken van de volgende vervoersmiddelen tijdens dit ongewoon hete en droge zomerweer?
(Een hokje aankruisen per vervoerswijze)

	veel minder				*veel meer*	*Weet niet/ N.v.t.*
A Openbaar vervoer	-2	-1	0	1	2	
B Eigen auto	-2	-1	0	1	2	
C Motor/scooter	-2	-1	0	1	2	
D Fiets	-2	-1	0	1	2	
E Wandelen	-2	-1	0	1	2	

6. Hebt U tijdens het ongewoon hete en droge zomerweer meer of minder gebruik gemaakt van:

(Een hokje aankruisen per activiteit)

	veel minder				*veel meer*	*Weet niet/ N.v.t.*
A Strand	-2	-1	0	1	2	
B Zwembad	-2	-1	0	1	2	
C Natuur (bijv. bos).	-2	-1	0	1	2	
D Sport faciliteiten buiten	-2	-1	0	1	2	
E Sport faciliteiten binnen	-2	-1	0	1	2	
F Theater/bioscoop/musea	-2	-1	0	1	2	
G Restaurants/bars binnen	-2	-1	0	1	2	
H Open lucht restaurants/ bars	-2	-1	0	1	2	

I *Anders* (vertel alstublieft wat)*:*

....	-2	-1	0	1	2

7. Bent U meer of minder dagjes uitgeweest tijdens de hete en droge zomer dan in een normale zomer?

	veel minder				*veel meer*	*Weet niet/ N.v.t.*
(Een hokje aankruisen)	-2	-1	0	1	2	

8. Bent U meer of minder op korte vakanties geweest tijdens de hete en droge zomer?

	veel minder				*veel meer*	*Weet niet/ N.v.t.*
(Een hokje aankruisen)	-2	-1	0	1	2	

9. Heeft de hete zomer Uw vakantieplannen beinvloed?

(Kruis alles van toepassing aan)

A Ja, ik heb mijn vakantieplannen van dat jaar aangepast	☐
B Ja, ik heb mijn vakantieplannen van het volgende jaar aangepast	☐
C Ik kan het me niet herinneren	☐
D Nee, ik heb mijn plannen niet gewijzigd	☐

10. Als het antwoord op vraag 9 ja is, hoe heeft U Uw plannen gewijzigd?

(Ktuis alles van toepassing aan)

A Thuisgebleven in plaats van op reis gegaan	☐
B Op reis gegaan in plaats van thuisgebleven	☐
C In Nederland gebleven in plaats van naar het buitenland gegaan	☐
D Naar het buitenland gegaan in plaats van in Nederland gebleven	☐
E Op een ander tijdstip met vakantie geweest	☐
F Meer vakantie genomen	☐
G Anders *(vertel alstublieft wat)*:	☐

....

11. In welk jaar vond de ongewoon hete en droge zomer plaats?

(Kruis het juiste hokje aan)

1990	1991	1992	1993	1994	anders……….
1995	1996	1997	1998		Weet niet

12. Is er iets <u>permanent</u> verandert in Uw levensstijl door de hete en droge zomer?

(Kruis zoveel hokjes aan als nodig)

A Ik breng meer tijd buitenshuis door	☐
B Ik vermijd de zon meer	☐
C Ik rijd minder auto	☐
D Ik rijd meer auto	☐

E Ik eet meer fruit en salade ☐

F Ik probeer minder water te gebruiken ☐

G Ik heb andere planten in mijn tuin ☐

H Ik neem vakantie op andere tijden in het jaar ☐

I Ik neem meer vakantie per jaar ☐

J Ik vaker op vakantie naar het buitenland ☐

K Anders (vertel alstublieft wat): ☐

....

13. Voor het hele land, hoe denkt U data de hete en droge zomer invloed heeft gehad op volgende gebieden?

(een hokje aankruisen per gebid)

	negatief				*positief*	*Weet niet*
A Gezondheidszorg	-2	-1	0	1	2	☐
B Landbouw	-2	-1	0	1	2	☐
C Watervoorziening	-2	-1	0	1	2	☐
D Wegverkeer	-2	-1	0	1	2	☐
E Luchtverontreiniging		-1	0	1	2	☐
F Natuur	-2	-1	0	1	2	☐
G Bosbranden	-2	-1	0	1	2	☐
H Productiviteit van het werk	-2	-1	0	1	2	☐
I Misdaad en openbare orde	-2	-1	0	1	2	☐
J Vrijetijd en toerisme	-2	-1	0	1	2	☐
K De economie	-2	-1	0	1	2	☐

Dank U voor het beantwoorden van de vragen over afgelopen hete zomers. We willen U nu een aantal vragen stellen met betrekking tot de toekomst.

14. Denkt U dat hete en droge zomers in de toekomst vaker voor zullen komen?

zeer onwaarschijnlijk *zeer waarschijnlijk* *Weet niet*

-2	-1	0	1	2		Weet niet

15. Stelt U zich voor dat hete en droge zomers vaker zullen voorkomen in de toekomst? Wat zoudt U daarvan vinden?

(Een hokje aankruisen per rij)

	-2	-1	0	1	2		Weet niet
erg onplezierig … *erg plezierig*							
erg alarmerend … *erg onbelangrijk*							

16. Als hete en droge zomers vaker zouden voorkomen, zouden er voor U dan positieve effect zijn?

ja *nee* *Weet niet*

ja	nee	Weet niet

Indien ja, welke?

(Kruis zoveel hokjes aan als nodig)

A Verbeterde gezondheid

B Mensen zullen socialer zijn

C Meer activiteiten in de open lucht

D Energierekening zal lager zijn

E Meer ontspannen levensstijl

F Anders *(vertel alstublieft wat)*:

....

17. Als er meer hete en droge zomers zouden zijn, zouden er voor U negatieve effecten zijn?

Ja *Nee* *Weet niet*

☐ ☐ ☐

Indien ja, welke?

(Kruis alles aan wat nodig)

A Gezondheidsproblemen ☐

B Mensen worder aggressiever ☐

C Misdaad neemt toe ☐

D Watertekorten ☐

E Slechte luchtkwaliteit ☐

F Anders *(vertel alstublieft wat)*: ☐

....

18. Zoudt U Uw gewoontes <u>permanent</u> veranderen maken als hete, droge zomers vaker zouden voorkomen?

(Kruis alles aan wat nodig)

A Ik zou meer tijd buitenshuis doorbrengen ☐

B Ik zou de zon meer mijden ☐

C Ik zou minder autorijden ☐

D Ik zou meer autorijden ☐

E Ik zou meer fruit en salade eten ☐

F Ik zou minder water proberen te gebruiken ☐

G Ik zou andere planten in mijn tuin zetten ☐

H Ik zou op andere tijden in het jaar op vakantie gaan ☐

I Ik zou vaker in Nederland op vakantie gaan ☐

J Ik zou vaker in het buitenland op vakantie gaan ☐

K Anders *(vertel alstublieft wat)*: ☐

....

Voor het beantwoorden van de volgende vragen willen wij dat U zich een ongebruikelijk warme winter voor de geest haalt.

19. Hoe werd Uw dagelijks leven beinvloed door de ongebruikelijk milde winter ?

(Een hokje aankruisen per gebied)

	negatief				*positief*	*Weet niet*
A Persoonlijk welzijn	-2	-1	0	1	2	
B Dagelijks verkeer	-2	-1	0	1	2	
C Vrijetijdsbesteding	-2	-1	0	1	2	
D Wintersport	-2	-1	0	1	2	
E Wintersfeer	-2	-1	0	1	2	
F Gezondheid	-2	-1	0	1	2	
	veel minder				*veel meer*	
G Huishoudelijk energie	-2	-1	0	1	2	
	negatief				*positief*	
H Luchtverontreiniging	-2	-1	0	1	2	
	veel minder				*veel meer*	
I Plagen (insecten, etc.)	-2	-1	0	1	2	

J. Anders (*vertel alstublieft wat*)

....	-2	-1	0	1	2

20. Welke van de effecten van vraag 19 is het <u>belangrijkst</u> voor **U**?

(Noem de letter)

21. Hoe voelt U zich in milde winters?

erg teneergeslagen				*erg blij*	*Weet niet*
-2	-1	0	1	2	

22. In welk jaar vond volgens U een ongewoon milde winter plaats?

(Kruis het hokje aan)

88/89	90/91	92/93	94/95	96/97	Anders?
89/90	91/92	93/94	95/96	97/98	Weet niet

23. Tot slot zijn wij benieuwd naar Uw mening over klimaatverandering. Vindt U het vooruitzicht van klimaatverandering:

erg zorgelijk *erg opwindend* *geen mening*

-2	-1	0	1	2	

We willen ook nog iets weten over U.

1. Waar woont U?

plaats

2. Waar woonde U tijdens de hete en droge zomer?

plaats

3. Bent U:

Man Vrouw

4. Hoe oud bent U:

A 16-24
B 25-34
D 35-44
E 45-54
F 55-64
G 65-74
H 75+

5. Wat bent U:

Nu *Tijdens de hete zomer*

A Student/scholier
B Huisman/vrouw
C Werkt buitenshuis

Beroep:

……………………………… ……………………………………

D Werkloos	☐	☐
E Met pensioen	☐	☐
F Arbeidsongeschikt	☐	☐
G Anders *(vertel alstublieft wat)*:	☐	☐

……………………………… ……………………………………

6. Heeft U een chronische aandoening aan de ademhaling, zoals asthma, hooikoorts of emphyseem?

   Ja ☐ Nee ☐

7. Overdag tijdens de hete zomer, was U voornamelijk:

   (Een hokje aankruisen)

A Buiten	☐
B Binnen zonder air conditioning	☐
C Binnen met air conditioning	☐
D Weet niet	☐

8. Heeft U

(Kruis alles aan wat nodig)

	Nu	*Tijdens de hete zomer*
A Een tuin?	☐	☐
B Een auto?	☐	☐
C Air conditioning in Uw auto?	☐	☐

9. Uit hoeveel mensen bestaat Uw huishouden?

   ☐

10. Hoeveel daarvan zijn onder de 16 jaar?

☐

Hartelijk dank voor de tijd en moeite. Zoudt U zo vriendelijk willen zijn de ingevulde vragenlijst in de bijgesloten enveloppe aan ons terug te sturen? Een postzegel plakken is niet nodig.

A1.2. Accompanying letter

Het Instituut voor Milieuvraagstukken (IVM) is een onafhankelijk onderzoeksinstituut, verbonden aan de Vrije Universiteit, dat een groot aantal milieuproblemen bestudeerd ten einde het milieubelied te verbeteren. Wij bestuderen momenteel de **effecten van klimaatverandering** in een project in opdracht van de Europese Unie. In het kader van dit project voeren wij een **enquete** uit in Nederland. Dezelfde enquete wordt ook gehouden in een aantal andere Europese landen.

Door middel van de bijgesloten vragenlijst willen wij uitzoeken **hoe de bevolking ongewoon weer beleeft en daarop reageert**. Bij ongewoon weer kunt U denken aan **wekenlange hitte en droogte in de zomer**, of **wekenlang mild winterweer**.

De beleving van het weer is tot dusver niet systematisch onderzocht. Wij verzoeken U daarom ons in ons werk te helpen door een paar minuten de tijd te nemen om de vragenlijst in te vullen. Uw antwoorden zijn erg belangrijk voor ons, ook als U niet alle vragen beantwoord. Stuurt U alstublieft de ingevulde vragenlijst in de bijgesloten envelop terug. Een postzegel plakken is niet nodig.

Uw naam en adres zijn willekeurig geselecteerd door de PTT. Alle antwoorden blijven anoniem.

U wordt nogmaals bedankt voor Uw medewerking.

Met vriendelijke groet,

Pier Vellinga
directeur